Appendix N
Impact Analysis of Ongoing Dry Cargo Residue Practices Based on Spring 2007 Data Collection

Impact Analysis of Ongoing Dry Cargo Residue Practices

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Introduction

The U.S. Coast Guard has investigated the influence of dry cargo residue (DCR) discharge to the Great Lakes on ecological conditions in the Great Lakes since the promulgation of the Interim Enforcement Policy (IEP). These investigations include the following:

- "Proceedings of the Workshop: The Environmental Implications of Cargo Sweepings in the Great Lakes" (Reid and Meadows, 1999)
- "A Study of Dry Cargo Residue Discharges in the Great Lakes" (U.S. Coast Guard, 2002)
- "Study of Incidental Dry Cargo Residue Discharges in the Great Lakes" (U.S. Coast Guard, 2005)
- "Scientific Approach for Dry Cargo Sweepings Impact Analysis" (Volpe National Transportation System Center et al., 2006a) and "Scientific Plan for Dry Cargo Sweepings Impact Analysis" (Volpe National Transportation System Center et al., 2006b)
- DCR studies conducted by CH2M HILL in fall 2006: chemical (2007a) and toxicological analyses (2007b), a biological characterization of nutrient enrichment (2007c), and an identification of sonar investigation sites (2007d)
- DCR studies conducted by CH2M HILL in spring 2007: a discharge analysis (2007e) and a depositional area characterization (2007f)

These studies have described existing DCR practices and procedures and documented ecological conditions in the areas of DCR discharge. However, only qualitatively have they evaluated the effects of DCR discharge on various segments of the Great Lakes ecosystem.

The purpose of this technical memorandum is to relate changes in ecosystem parameters to DCR discharge as measured or predicted as part of the U.S. Coast Guard's investigations. The impacts from past and ongoing DCR practices are documented for the segments of the ecosystem that, as explained below, were determined to be potentially influenced by the discharge of DCR:

- Water quality
  - Chemistry
  - Nutrient enrichment

  - Dissolved oxygen
- Sediment quality
  - Chemistry
  - Physical structure
  - Deposition rate
- Biological resources
  - Fish and other pelagic organisms
  - Benthic community
  - Waterfowl

The impacts from DCR practices identified in this memorandum will be incorporated into the Draft Environmental Impact Statement (DEIS) currently under preparation by the U.S. Coast Guard as part of the DCR management rule making. Specifically, the results identified in this memorandum will be used to describe the impacts associated with the DEIS alternative of continuing the existing IEP, because the measurements used here were taken during a period preceded by over 15 years of adherence to the IEP. The results will also be used to predict impacts of alternative methods of managing DCR evaluated in the DEIS. Since the other alternatives are generally modifications of the existing IEP, the predicted impacts of these other alternatives will be modifications of the impacts measured for adherence to the existing IEP. For example if an alternative would result in reduced discharge of DCR, the predicted impact for the alternative would be proportionately less than that measured and reported in this memorandum.

Impact Conceptual Model

The first step in impact prediction is to conceptualize the practice under evaluation. This conceptualization is used to identify potential pathways and mechanisms associated with the practice that could alter components of the ecosystem. Through review of past studies, discussions with Great Lakes scientists, discussions with Lake Carrier operators, and observations of DCR practices, a conceptual model of how the discharge of DCR could interact with ecological resources was developed (Figure 1).

The potential interaction between DCR and the ecosystem begins with DCR discharged from the ship, from either sweeping of the deck or pumping of the sump (low lying wet sumps in tunnel under the cargo holds collect cargo residue and wash down water and are typically 100-200 gallons each; the total number of sumps depends on the design of the individual vessel). This material then enters the water column, where it can potentially alter the chemical characteristics of the water, affecting the dissolved oxygen concentration, nutrient concentrations, or contaminant concentrations. After a relatively short residence time in the water column, the DCR solids settle to the lake bottom and incorporate into the sediments. The settling can alter the sediments physically by adding hard particles to the typically soft mud on the lake floor. The DCR can also add contaminants and thus change the chemistry of the sediments or otherwise change the habitat by increasing the rate of solids deposition on the bottom.

The physical, chemical, or enrichment alterations of the water column or sediments can in turn affect the biological resources residing in the water column or sediments (Figure 1).

This can change the characteristics of the benthic (residing in the sediments) organisms or pelagic (residing in the water column) communities. The changes can result either from changes in physical habitat or from the addition of contaminants that could be toxic to the biological resources. The alterations could also move through the system and affect organisms, such as waterfowl, dependent on either the pelagic or benthic community.

Scientific investigations were designed (Volpe National Transportation System Center et al., 2006a) and conducted (CH2M HILL, 2007a-f) to determine if the potential impacts identified in the impact conceptual model (Figure 1) are occurring. Virtually all scientific investigations are limited in spatial and temporal coverage and thus represent just a "snapshot" of the conditions of interest. The DCR investigations are no exception, and thus there is some degree of uncertainty in applying the results to broader geographic coverage and duration. In order to minimize the uncertainty, more than one investigation was designed to assess each potential area of impact, thus constituting a multiple line of evidence approach (Figure 2). If each line of evidence yields the same conclusion regarding the existence or degree of impact, there is more certainty and confidence in the prediction.

Although there are numerous types of DCR and discharges occurring in all the Great Lakes, previous studies (Reid and Meadows, 1999; U.S. Coast Guard, 2002; U.S. Coast Guard, 2005) have indicated that the extent and intensity of impact is not the same for all DCR materials or for each lake. Most (84–99 percent) of the bulk cargo shipped on the lakes comprises iron ore (i.e., taconite), coal, and limestone (Table 1). Cement and grain are the only other materials comprising 3 percent or more of the cargo shipped, and the percents of these commodities are much less when only U.S. flagged ships are considered (1998–2004 data from e^{2}M [2005]; Table 1]). In addition, these materials reflect a much lower percent of the discharge than they do of the cargo because of the handling practices of grain and cement. Grain and cement are loaded and unloaded using totally enclosed pumping systems, so there is little if any spillage and thus very little DCR discharged during deck- or tunnel-cleaning operations. In recent years, commodities other than iron ore, coal, and limestone, such as salt, grain, coke, cement, milliscale, slag, sand, and potash have accounted for <1% to 16% of the total cargo shipped annually (Table 1).

A review of the chemical characteristics of DCR (U.S. Coast Guard, 2002) reveals that if any type of DCR had metal concentrations that could affect water quality or cause toxicity it would be iron ore (taconite). Similarly, if organic chemical contaminants were present in DCR at concentrations that could affect water quality or toxicity, it would be in coal DCR, and if physical alteration of the sediment were present from particularly large, dense particles in soft mud, it would be greatest with limestone DCR. Thus if current DCR practices had an impact, they would be greatest from iron ore, coal, and limestone, and DCR management methods to control impacts from these materials would also control impacts from other types of DCR. The workshop held by NOAA (Reid and Meadows, 1999) reached the similar conclusion: that if DCR discharged to the lake had an impact; it would be most noticeable from these materials.

Two areas where DCR impacts could be greater from materials other than iron ore, coal, and limestone were considered. One is enrichment from discharge of material high in organic content, such as grain or forest products. However, as presented above, grain is handled in an enclosed environment with little or no spillage, and the volume of forest products shipped and discharged is very low (it does not appear in quantifiable amounts in ships' records from 2001 or 2004). Thus, these materials were not studied in detail.

The second area of potential impacts that might not be fully addressed by examining iron ore, coal, and limestone is localized change in water chemistry from the discharge of salt. Salt is carried primarily on Canadian vessels and for all the Great Lakes can be as much as 41,000 pounds a year (compared to 1,805,474 pounds a year for iron ore, coal and limestone) (U.S. Coast Guard, 2002). Salt contamination would not be a concern in the water column, because either it would not dissolve at all or even if it dissolved completely, the dilution would be several thousand to one. The result in either case would not measurably raise the salinity of the water, and no impacts would occur. If the salt did not dissolve in the water column, it could come to rest in the sediments, where it would dissolve over time and be diluted by the water around it. If the salt crystals dissolved slowly, no impacts would occur because of dilution. If dissolution was rapid, there could be a localized issue within a few centimeters of the salt crystal. The rate of dissolution depends on the temperature, pH, and the conductivity of the water.

DCR discharge occurs in all of the lakes but at very different rates. The rate of discharge in each lake was evaluated for each DCR material and the areas of the greatest discharge per acre were identified (U.S. Coast Guard, 2002). This information, along with other information regarding the lakes and DCR operations, was evaluated in detail to identify the specific areas within the Great Lakes where the impact could be the greatest (Volpe National Transportation System Center et al., 2006b). This analysis took into consideration the differences in habitat among the lakes, and the areas identified with the highest discharge rates represent common habitat types within all of the Great Lakes.

The identified areas were the focus of the detailed sampling and analysis conducted to support this impact evaluation. As described below, each of the areas of greatest DCR discharge were sampled and analyzed to characterize the physical, chemical, and biological aspects of sediments. These areas were sampled because if lake sediments were affected by DCR discharge, the effects would be greatest in the areas with higher documented discharge rates. Effects in other areas from DCR discharge would be less; thus, impacts documented based on these selected areas would represent the greatest expected impacts. If no effects were detected in these areas, none would be expected in other areas. Similarly, measures to mitigate impacts from DCR discharge determined for the identified areas would be equally effective in areas with a reduced rate of discharge.

Water Quality

As described above, the first area that could be potentially impacted from DCR discharge is the water column. As the DCR mixes with the water, there is the potential for chemicals from the DCR to dissolve in the lake water and exceed water quality criteria; enrich the water with nutrients; or add organic manner, thus increasing the oxygen demand, which can result in lower dissolved oxygen concentrations. The dilution of the DCR once it enters the lake determines the concentration of the compounds found in the DCR and their associated impact on water quality. Thus the first step in evaluating the impact in the water column was to determine the dilution of the DCR discharge. This determination was made using a mathematical simulation that is described in detail in CH2M HILL (2007e) and summarized below.

A review of modeling computer software packages determined that few complex modeling applications would apply to DCR discharge to the Great Lakes; thus, the Simple Dilution Model was used to estimate dilution of the DCR discharges with lake water. The Simple Dilution Model was developed by an independent science advisory panel to assist the Alaska Department of Environmental Conservation in evaluating the effects of wastewater discharges from cruise ships in Alaskan waters (Loehr et al., 2003). The model proved to be the most useful and applicable of all those evaluated.

The cruise ships analyzed in Loehr et al. (2003) had beams of about 100 feet, drafts of 25 feet, and speeds ranging from 9 to 19 knots, which are specifications very similar to the large cargo vessels traveling on the Great Lakes. Great Lakes cargo vessels generally have 70- to 100-foot beams, 30 feet of draft or less, and can travel at speeds up to 17 knots (Great Lakes et al., 2007). Wastewater discharge rates for cruise ships range from 250 to 500 gpm, which is similar to the 300-gpm flow from a typical wash-down hose onboard a cargo vessel (CH2M HILL, 2007a).

In August 2001, the U.S. Environmental Protection Agency (EPA) conducted a dye study of the discharges of four cruise ships to validate the Simple Dilution Model. The model proved a conservative model, as the actual observed dilution factors were greater by up to 40 percent than those predicted by the model were. Research on wastewater discharges from cruise ships has shown that a dilution factor of at least 12,000 can be expected within 15 minutes behind a large cruise ship (Alaska DEC, 2001).

Two types of discharge were modeled for each DCR of concern (taconite, coal, and limestone). One was the liquid collected from the sumps of lake carriers, as described by CH2M HILL (2007a). The other was deck sweepings, which were simulated from solid DCR collected from the ships’ deck and calculated based on ratios of water to deck DCR sweepings that were presented in CH2M HILL (2007a).

The Simple Dilution Model was used to predict the dilution of discharge in the water column due to both DCR deck and sump discharges. The mass of discharged deck DCR sweepings was taken as the average discharge obtained from the 2004 data (USCG, 2005) and done separately for each type of DCR. The largest sump on the studied coal vessels was roughly 12 yd3 (2,424 gallons), and the largest sump on the studied taconite vessels was 1.2 yd3 (242 gallons); these were used as the volumes for these types of DCR. The sample from the limestone sumps did not show any water quality exceedances (see the water chemistry section, below); therefore dilution is not required to discharge this material. Volumes larger than the sump volume are also discharged when the tunnels within the hull of the vessel, used for unloading DCR, are flooded during wash-down events; however, individual discharge rates are limited by sump pump capacity. The discharge rate of the sump slurry was assumed to equal 400 gpm, and the duration of pumping was conservatively estimated (i.e., the largest discharge that could realistically occur) at 10 minutes. This yielded a discharge volume of 4,000 gallons, which is much larger than the sump. The calculated dilution ranged from 27,000 to 62,000 to 1, depending on type of DCR (Table 2). These are minimum estimates of dilution because currents, substantial winds, or hull or propeller wash would increase the dilution. This means that approximately 15 minutes following the discharge, there are between 27,000 to 62,000 parts of water for every one part of deck slurry or sump liquid in the water column behind the vessel.

Water Chemistry

If water chemistry is changed sufficiently by increasing the lake water concentration of chemicals found in DCR, there can be impacts to aquatic biota and other lake ecosystem components. The presence of an impact is determined by comparing the lake water concentrations to chronic and acute water quality criteria obtained from the Great Lakes Initiative and the EPA for the protection of aquatic life and human health. Criteria are established for both long-term (chronic criteria) and short-term (acute criteria) exposure. Acute criteria are generally applied for the protection of aquatic biota that might pass closely to a discharge but be exposed only for hours to days. The analytical results of liquid sump samples and simulated deck sweepings that were collected from eight bulk dry cargo vessels (CH2M HILL, 2007a) were used to evaluate the change in lake water concentration, and thus water chemistry impact from DCR discharges.

The first step to evaluating the water chemistry impact was to compare the measured concentration in the sump liquid or simulated deck sweeping, before any dilution, with the most stringent water quality criteria. This was a useful comparison from a screening perspective, because discharged parameters that meet criteria even without consideration of applicable dilution can be regarded as parameters that do not require further impact assessment. The highest exceedance of acute water quality criteria in the undiluted sump liquid or simulated deck sweepings was by a factor of 1.9 and most of the chemical concentrations were below the acute criteria. This means that the discharge would have to be diluted by only an equal volume of lake water (i.e., a dilution of 1) to meet the acute criteria of any chemical in the DCR discharge. Since the DCR discharge was estimated to be diluted at least 27,000 times after 15 minutes, all acute criteria would be met within seconds of discharge.

There are only three instances in which chronic water quality criteria were exceeded in undiluted samples by more than a factor of 10, and the highest exceedance was by a factor of 31 for pyrene (Table 3). The highest pyrene concentration measured in any discharge was 0.43 μg/L, or 43 parts per billion, compared to a water quality criterion of 0.014 μg/L. If the discharge were diluted with clean water at the minimum predicted dilution (27,000 times), the resulting concentration after 15 minutes would be approximately 1.6×10^{-5} μg/L. Even if the receiving water was at 99 percent of the criterion (i.e., 0.01386 μg/L), the concentration after mixing of receiving water and discharge would be only 0.01388 μg/L, which is still below the criterion.

The discharge of DCR would not result in any exceedances of water quality criteria even for the chemical with the highest concentration in relation to criteria and even if the receiving water was already very close to the criteria. This analysis represents only limited sampling, but of the ships sampled there was only minimal variability (CH2M HILL, 2007a); thus although there is uncertainty in the analysis, it is considered representative. Since the prediction is well below the threshold of impact (approximately 27,000 times), there is little uncertainty in the concluding that discharge of DCR from the tunnel sump or deck would not have an impact on water chemistry.

Dissolved Oxygen

Organic matter in the DCR discharge can be used as food by bacteria and other microorganisms in the lake water. As the organisms use this food, they respire, which consumes the dissolved oxygen in the water. This is a natural process and indeed essential for the ecosystem to function. However, if there is an excess of organic matter, the process proceeds at an unnatural rate, and the oxygen can be depleted to levels below that required to sustain fish and other organisms present in the lake water. The potential for this impact to occur is dependent on the amount of organic matter present in the DCR and subsequently in the lake water.

Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were measured in the sump liquid and simulated deck sweepings from the eight vessels sampled (CH2M HILL, 2007a). Neither BOD nor COD were detected in any of the simulated deck sweepings, and in only one of the sump liquid samples (25 mg/L total BOD and COD, which is what might be expected in stormwater runoff). The simulated deck sweepings is considered to be more reflective of DCR because the sump liquid often contains oil and other substances associated with ship operations in the tunnel. For the maximum concentration measured, after the minimum predicted dilution of 27,000 times, the oxygen demand in the receiving water would be well below detectable levels. Even with uncertainty associated with the limited number of samples, the low level of impact predicted on dissolved oxygen strongly indicates the absence of any impact on water quality.

Nutrient Enrichment

As described above, there is the potential for a discharge to stimulate biological activity, which can have implications on ecosystem function. Just as the addition of organic material can stimulate bacterial activity, addition of inorganic nutrients (particularly phosphorous and nitrogen) can stimulate aquatic plant growth. Plant growth is essential to ecosystem function because it forms the base of the food web. However, an excess of it can alter the ecological balance, particularly by creating so much respiration from the excess food that dissolved oxygen is severely depleted. The potential for adverse stimulation of plant growth was examined from two perspectives: increase in nutrient concentration and laboratory testing of increased aquatic plant growth. Both of these are described in detail by CH2M HILL (2007c) and summarized below.

In general, there was little difference between nutrient concentrations in simulated DCR slurry and the lake water. Of all the forms of nitrogen and phosphorous measured (N03, NH3, TKN, TN, OP, and TP), all the DCR analyzed (iron, eastern coal, western coal, and limestone), and both lakes tested (Superior and Erie), there were only six cases where the slurry had higher concentrations than the lake water (Table 4). Of the cases with significantly higher nutrient concentrations in slurry, only total phosphorus in western coal for Lake Erie was substantially higher (five times higher, with Lake water at 0.02 mg/L and the slurry at 0.13 mg/L). The other five cases of higher nutrient concentrations in the slurry were less than twice the lake water concentrations. After dilution (at least 27,000 times, as described above), there would be no measurable change in nutrient concentrations resulting from DCR discharge.

The potential for DCR discharge to stimulate aquatic plant growth was also assessed. The assessment was made by introducing phytoplankton (small, free-floating aquatic plants) into an aliquot of water from Lakes Erie and Superior and then measuring the increase of phytoplankton as indicated by increased chlorophyll concentration after 4 days. Similarly, the phytoplankton were introduced into DCR slurries simulated with water from Lake Erie and Lake Superior. The tests on simulated slurry were done with 100 percent, 50 percent, and 10 percent slurry, with the balance of the test material made up of lake water.

Minor increases in phytoplankton activity were seen in several of the slurry-type cases for both lakes (Figures 3 and 4). Western coal and limestone produced little or no response for either pure slurry or the dilutions in either lake. Eastern coal and taconite generally produced an increase of approximately 50 percent with the pure slurry and much less with the 10 percent slurry. Since neither of these materials showed an increase in primary nutrients (Table 4), it is likely that the increases observed were due to micronutrients such as iron.

Although DCR can produce slightly increased aquatic plant production when introduced at high concentrations, the effects are diminished at dilutions of even 10 to 1 (i.e., the 10 percent slurry test), and no change is expected at dilutions expected from DCR discharges (i.e., at least 27,000 to 1).

Sediment Quality

As discussed above, the residence time of DCR in the water column is short, and no measurable impacts are predicted in the water column. In contrast, the ultimate fate of most DCR discharge is the lake bottom, where there is the potential for accumulation and thus impacts to the sediment quality. DCR can have an impact on sediments by increased depositions and alteration of the physical or chemical characteristics of the sediment. The potential for each of these types of impact is addressed below.

Sediment Deposition Rate

The impact of DCR deposition is gauged by how it compares to natural sedimentation rates. The natural rate varies considerably both among and within lakes (Table 5). The lakes with larger volumes (e.g., Lake Superior) have lower natural deposition rates, and the smaller lakes with more developed shorelines (e.g., Lake Erie) have the highest rates. Within lakes, the nearshore areas receive the land-based soil particles via stormwater runoff and thus have the highest deposition rates. In contrast, the central portions of lakes have reduced land-based input and have substantially lower deposition rates.

The DCR deposited within shipping tracklines was estimated from ships logs for 2001 (U.S. Coast Guard, 2002). The estimated deposition rates for all types of DCR combined and all lakes ranged from 6.449 to 0.086 lb/acre/year, which converts to 0.72 to 0.01 g/m^2/year on average in various segments of shipping tracklines. This is approximately 0.2 percent or less of the natural deposition rate (Table 5) and only a small fraction of the variation within lakes. The benthic, or sediment-dwelling, organisms have evolved to tolerate the natural sedimentation rates, and such small increases would not have an impact on the sediment environment. There are instances where this average is exceeded, and this could produce temporary impacts in small areas. However, the limited spatial and temporal nature of the effects would be insignificant in relationship to the shipping trackline and of the entire lake.

Sediment Physical Structure

The physical structure of the sediments was evaluated by assessing the potential for DCR discharges to alter the composition of the sediments to the degree that the habitat for benthic organisms would be adversely affected. This impact was evaluated by comparing grain size distributions of sediments in DCR discharge and reference areas.

Sediment samples were collected from five shipping tracklines (two in Lake Superior, one in Lake Michigan, and two in Lake Erie) and analyzed for chemical and physical parameters, as well as tested toxicologically. Each trackline consisted of a DCR discharge area and a reference area. Large, high-intensity DCR discharge areas (approximately 10 miles long and the width of the shipping lane) were selected based on ships' logs showing the areas of greatest DCR sweeping and discharge activity. These areas were then surveyed using multibeam sonar and precise sampling locations were determined based on the presence of acoustical anomalies that may indicate the presence of concentrated DCR on the sediment surface (Habitat Solutions, 2006; CH2M HILL, 2007d). Acoustical anomalies varied in size and appear to have been successfully targeted for most samples in both Lake Superior tracklines and one trackline in Lake Erie (Marblehead). The acoustical anomalies in Lake Michigan and Lake Erie (Cleveland) may not have been as successfully targeted (CH2M HILL, 2007f). The successful targeting of the acoustical anomalies was also determined by the presence of DCR in the sediment. All DCR discharge area sediment samples had more DCR than did those samples from reference areas. The greatest amounts of DCR were observed in a Lake Superior (Duluth) DCR discharge area sample and a Lake Erie (Cleveland) DCR discharge area sample.

The results of the grain size analysis for sediment collected in the DCR discharge areas and reference areas are presented for each lake in Figures 5 through 9. DCR collected from the deck of cargo vessels is also shown on the figures, with types of DCR not distinguished because they all have similarly sized particles (larger than 0.05 mm). In general, the grain sizes in DCR discharge areas were similar to sediment in reference areas and not similar to the grain size of deck DCR samples (i.e., larger than 0.05 mm), with some exceptions. Lake Michigan sediment grain sizes in both DCR discharge and reference areas appear larger and more similar to deck DCR samples grain sizes than sediment grain sizes in Lake Superior and Lake Erie. Some samples also contained a small percentage of larger particles that are similar in size to deck DCR samples. A Lake Superior (Duluth) DCR discharge area sample contained approximately 15 percent more particles within the 3.35- to 19-mm range than other samples within the Duluth trackline. A Lake Erie (Marblehead) DCR discharge area sample contained approximately 20 percent more particles within the 0.6- to 1.18-mm range than other samples within the Marblehead trackline. Similarly, Lake Erie (Cleveland) DCR discharge area sample contained approximately 15 percent more particles within the 0.6- to 1.18-mm range than other samples within the Cleveland trackline. As previously indicated, the greatest amount of DCR (coal) was observed in this sample. This sample also had considerably higher total organic carbon than the reference area samples.

Based on these results, impacts to sediment physical structure, defined as noticeable grain size differences among sediments from DCR discharge areas, may occur in at least some areas of intense DCR discharge. These impacts are likely insignificant because the increased heterogeneous grain size distribution provides increased habitat diversity relative to that of reference areas.

Sediment Chemistry

When material is added to the lake bottom, even in small amounts, there is the potential for the chemistry of the sediment to change, which can produce toxicity to the organisms in the sediment or disrupt sediment processes such as decomposing organic matter or regenerating nutrients to facilitate photosynthesis. This represents a major potential for impact because the sediment is the final resting place for the DCR, and any changes in chemistry can be cumulative. Because of the potential for significant impact from alteration of sediment chemistry, this was a major focus of the impact evaluation for DCR discharge. The evaluation consisted of three independent analyses to produce three lines of evidence, because each line has inherent uncertainty, but taken together the uncertainty is greatly reduced. The three types of analyses employed were the following:

- Mathematical calculation of sediment concentrations of concern based on DCR discharge rates
- Measurement of DCR chemistry and toxicity
- Measurement of sediment chemistry and toxicity in areas of greatest DCR discharge

Each of these analyses is discussed below.

Calculation of Sediment Concentrations of Concern. DCR discharge, from both long-term and single events, was evaluated to estimate concentrations in sediments using multiple approaches. One evaluation was based on the annual discharge of DCR combined with the annual natural deposition, but no mixing with in-place sediments. Another evaluation assumed mixing of DCR discharged over 100 years and the top 2 inches of sediment with no natural deposition. The final evaluation considered the single largest event over the smallest area listed in DCR discharge records (U.S. Coast Guard, 2002). All approaches incorporated conservative assumptions in the evaluation so that any inaccuracies in the calculations would tend to overestimate rather than underestimate sediment concentrations. The evaluations were also based on the chemical found at the highest concentration in any deck or cargo DCR sample type relative to the criterion (naphthalene, by a factor of 17.6 times greater than the criterion for the maximum concentration and of 3.6 times greater for the average concentration). Thus the analysis is based on the worst case in the data record and impacts from any other chemical would be less. The evaluations are described in detail by CH2M HILL (2007e) and summarized below.

The addition of naphthalene to the sediment was calculated using the total discharge of coal from the 2001 DCR record (U.S. Coast Guard, 2002) for each lake. If all of the coal DCR for a given lake was discharged over 10 miles of shipping trackline at a width of 375 m or greater and mixed with natural sediment deposition over one year,[1] there would be no exceedance of criterion for naphthalene. In reality, coal DCR sweeping discharges over an entire year are spread over an area much larger than 10-miles by 1,230-feet (375-meters) because in a given year not all ships on the track line would clean the decks or sumps in the same 10 mile linear distance or in the same location relative to the center of the track line. Individual DCR discharges from moving cargo vessels spread out because of wake turbulence. Large cargo vessels can be up to 98 feet (30 meters) in width, and the turbulent zones behind the ships

[1]For Lake Superior; other lakes are less because the natural sedimentation rate is greater in the other lakes.

are about 2.5 times greater than the ship width (Loehr et al. 2003). Thus the width of an individual discharge would be at least 245 feet and all the discharges on a track line would be over a much wider area. Since naphthalene was found at the greatest concentration relative to the criterion, no other chemicals would exceed criteria under these circumstances. Review of DCR discharge records (U.S. Coast Guard, 2002; U.S. Coast Guard, 2005) reveal that the actual area of discharge is much greater than these dimensions, thus no exceedances of sediment criteria based on this mathematical simulation are anticipated.

A similar analysis was performed to predict concentrations in sediment assuming no natural deposition but mixing of the DCR with the top 2 inches of in-place sediments. Whereas the previous analysis was done on a yearly basis, this analysis was done over a 100-year duration. The analysis revealed that if all DCR for Lake Superior was deposited within a 10-mile long and 150-meter wide area or greater, this would result in sediment concentrations below criteria for all chemicals detected in any DCR type. The area required in other lakes would be even less because the greatest amount of DCR is discharged in Lake Superior. This analysis also supports the conclusion that long-time discharge of DCR would not result in sediment quality exceedances.

The above analyses addressed the potential for sediment impact based on long-term discharge of DCR but there is also the possibility of a one-time event increasing the sediment concentration above criteria in a small area. The potential for this impact was evaluated by assuming that a large single discharge of coal (i.e., 92 lb/mile, which is the 99th percentile value in the 2001 database) occurred and combined over 1 year with the naturally deposited sediment. For the chemical in any DCR type with the highest concentration relative to criteria (i.e., naphthalene) to be below the criteria in the sediment, the width of discharge would have to be only 2.1 m wide. Since the lake carriers are at least 20 m wide, a discharge width of at least 2.1 m is assured. Another coal discharge within a year would have to occur in the exactly same 2.1-m by 1-mile area for any sediment criterion to be exceeded.

Based on calculations of DCR mixing with sediments using conservative assumptions (and a safety factor of 10), no impacts on sediment chemistry are anticipated. This is due to the relative low concentrations of potentially harmful chemicals in the DCR and the low rate of DCR deposition relative to natural sedimentation. This theoretical prediction was tested by analyzing the DCR and the sediments where the DCR is deposited as discussed below.

DCR Solids Chemistry and Toxicity. DCR sweepings samples were collected from the decks and sumps of vessels carrying coal, taconite, and limestone and analyzed chemically CH2M HILL, 2007a). This evaluation represents a hypothetical situation, in which the sediments on the lake floor, under the discharge, are 100 percent DCR. This situation could never occur, but if the chemistry and toxicity of 100 percent sweepings does not represent an impact, then there would be no impact once the DCR is mixed with in-place sediments in proportions discussed above (DCR representing 0.1 percent or less of natural deposition; see Table 5). The data obtained from the chemical analysis were compared directly to sediment guideline values. Sediment guideline values are the freshwater consensus-based threshold effects concentrations from MacDonald et al. (2000). Threshold effects concentrations are defined as the concentrations below which adverse effects are not expected.

Chemical analysis of the solid DCR sweepings obtained directly from the sumps and decks of various ships showed that only the DCR sweepings from the decks exceeded sediment criteria. Chemical concentrations in the taconite and limestone DCR sweepings were below the sediment criteria for all analytes. Most of sediment criteria exceedances were associated with samples of coal deck DCR sweepings that exceeded criteria for polycyclic aromatic hydrocarbons (PAHs) such as naphthalene and chrysene, with at least one PAH exceedance from all ships sampled. As stated above, the highest single exceedance ratio was in a sample of deck DCR sweepings from an eastern coal vessel that exceeded the naphthalene criterion by a factor of 17.6.

There were only three instances in which a DCR sweepings solids sample exceeded the sediment criteria by more than a factor of 10. Two of the values were copper samples collected from two different sumps on the same western coal vessel. The third exceedance was the naphthalene exceedance. The two copper exceedances are not representative of typical DCR discharges described above. The samples of sump solids appear to be high in overall metals because of the potential inclusion of foreign metallic objects. Observations during sampling confirm that bolts, screws, wires, and other foreign matter were present in the sumps (CH2M HILL, 2007a). These objects are likely the cause of the high values of several metals analytes observed in the sump solids. All other sediment exceedances (below a factor of 10) were found in samples of deck sweepings.

Dry deck sweeping solids and the sweepings diluted with clean sediment were also tested toxicologically with the midge (*Chironomus dilutus*) and the amphipod (*Hyallela azteca*) in chronic bioassays (20 days and 28 days, respectively) to conservatively simulate exposure to accumulated sweepings deposits on the lake bottom (CH2M HILL, 2007b). Both species were tested with 100 percent DCR and *H. azteca* was tested in a mixture of 10 percent and 50 percent DCR mixed with clean sediment. The purpose for testing the mixture was to determine if combining the DCR with native sediments, as would occur for an actual discharge, would alter the response of the organism in the test. Ten percent DCR was used instead of a value closer to what occurs in the lakes (i.e., 0.1 percent) to over estimate impact and because the purpose was to determine if toxicity test organism responses changed when the DCR was diluted and not to measure actual DCR concentrations. Consistent toxicity was not observed across bioassays, which may suggest sensitivity differences among the test species to the physical and chemical properties of the DCR. For chironomids, mortality was observed in taconite exposures, and growth impacts were observed in an eastern coal samples. However, no chemical constituents in the taconite sample exceeded sediment guideline values. In the eastern coal sample, there were slight exceedances of the guideline values for arsenic, chrysene, naphthalene, phenanthrene, and pyrene (all hazard quotients were less than 5.0). For the *Hyallela* bioassays, where toxicity was observed in several samples, there were also few exceedances. The lowest *Hyallela* survival was observed in western coal, but there were only slight exceedances of sediment benchmarks for benzo(a)anthracene, phenanthrene, and pyrene in this sample.

The DCR samples mixed with native sediments showed considerably less mortality or fewer growth effects than in the 100 percent DCR samples. The results of the *Hyallela* dilutions are shown in Figure 10. For all samples except an eastern coal sample, significant effects on survival as compared to the control were observed in all 100 percent DCR samples, but the effect on survival was considerably reduced at 10 percent for all samples except a limestone sample. The limestone sample had similar results for all dilutions and had no constituent that exceeded screening guidelines values, which suggests that chemical factors were not involved.

Based on these results, it does not appear that chemical constituents in DCR are associated with toxicity, as a consistent negative relationship with chemical concentration was not observed. While undiluted DCR discharge may produce toxicity from chemical exposure, under realistic dilution scenarios, the effects are similar to control sediment. Reduced performance (i.e., significant reductions from the laboratory control) in undiluted DCR is most likely the result of a combination of chemical and physical factors that are not readily distinguishable.

Sediment Chemistry and Toxicity. As described above, sediment samples were collected from five shipping tracklines (two in Lake Superior, one in Lake Michigan, and two in Lake Erie) and analyzed for chemical and physical parameters, as well as tested toxicologically. The data obtained from the chemical analysis were compared directly to sediment guideline values.

In all the lakes, sediment concentrations of inorganics and PAHs in both DCR discharge areas and reference areas were very similar. Concentrations of some inorganics were elevated above screening guideline values in both areas and in all lakes, but within the range identified by other investigators for the open water sediments in the Great Lakes (Mudroch et al., 1988) (Table 6). Sediment PAH concentrations in DCR discharge areas were rarely above criteria and very similar to those in reference areas.

For Lake Superior, concentrations of arsenic, cadmium, copper, lead, nickel, and zinc exceeded screening guideline values in the DCR discharge and reference areas, with no observable difference between the two areas. Concentrations of PAHs were low in all samples and did not exceed guideline values in any sample. As previously mentioned, a greater amount of DCR (taconite) was observed in a Lake Superior (Duluth) DCR discharge area sample, but the presence of more DCR (taconite) in this sample did not appear to affect levels of any constituent measured, including iron.

For Lake Michigan, as for Lake Superior, concentrations of arsenic, cadmium, copper, lead, nickel, and zinc were elevated above screening guideline values in both DCR discharge and reference area samples. The highest concentrations of these constituents were observed in a DCR discharge area sample (approximately two times higher in this sample than in the reference area sample). PAHs were also higher in this sample than in the other DCR discharge area samples, but the highest levels of PAHs were observed in a reference area sample.

For Lake Erie, concentrations of arsenic, cadmium, copper, lead, nickel, and zinc exceeded screening benchmarks in both the DCR discharge and reference areas. Concentrations of PAHs were low in all samples, and were only detected slightly above benchmarks in one Lake Erie (Cleveland) DCR discharge area sample and a Lake Erie (Cleveland) reference area sample. As previously mentioned, a greater amount of DCR was observed in Lake Erie (Cleveland) DCR discharge area sample, but the presence of more DCR (eastern coal) in this sample did not appear to affect levels of any of the constituent measured. For chemicals without screening benchmarks, only calcium, in a Lake Erie (Marblehead) DCR discharge area sample, appeared elevated, possibly due to a large number of juvenile mussels in the sample.

Clyne (2000) evaluated metal concentrations in DCR discharge areas in Lake Ontario and observed that average concentrations in sediments with DCR were significantly lower than average metal concentrations in reference area sediments. The lower metal concentrations in DCR discharge area sediments were attributed to the relatively high density of DCR particles, which had lower metal concentrations than sediments in the reference area. This conclusion is supported by comparing concentrations in the sediment samples collected by Clyne (2000) to concentrations in DCR solids collected in October 2006 (CH2M HILL, 2007a) (Table 7). For all parameters measured, sediment concentrations had higher levels than DCR solids.

Sediment samples were also tested toxicologically with the midge (*Chironomus dilutus)* and the amphipod (*Hyallela azteca*) in chronic bioassays (20 days and 28 days, respectively) (CH2M HILL, 2007f). Survival and growth were measured for each test species at test completion. Although results from both DCR discharge areas and reference areas showed survival and growth differences significantly below the laboratory control for many samples, there were few differences between the DCR discharge area and the reference areas (Figures 11 through 14). In Lake Michigan, *Hyallela* growth was significantly reduced when compared to one of the reference area samples. However, the high level of growth in the reference area sample is most likely a result of density dependence, as this sample also had the lowest survivorship of all samples, thus more food was likely available for growth of the surviving organisms. In Lake Erie, chironomid survival in one of the Marblehead DCR discharge area samples was significantly lower than the reference sample. In the other DCR discharge area sample from Lake Erie, growth was significantly less than the reference area sample. In both of these Lake Erie samples, small coal fragments were observed.

Although statistically significant adverse effects were found in DCR discharge areas relative to the response of test organisms in reference areas, which suggests an impact, the effects observed do not appear to be associated with any chemical constituent. As described above, several constituents (mostly inorganics) exceeded screening criteria in both DCR discharge and reference area samples, but the magnitude of the constituent does not appear to be related to reduced growth or survival of test organisms in the toxicity testing. For DCR discharge area samples in Lake Erie (Marblehead), which had significantly lower average organism growth and survival, constituents that exceeded criteria also exceeded criteria in the reference area samples by the same or similar magnitude.

In comparison to the results from the deck DCR sample toxicity testing, *Hyallela* survival was lower in sediment from both DCR discharge and reference areas as compared to most types of DCR (coal, taconite, and limestone; the 10 percent dilutions were used for comparison). *Hyallela* growth was very similar in DCR discharge and reference area sediment and deck DCR sample, except for taconite, which was generally higher than in sediment. Chironomid survival was very similar to average survival in all types of DCR, whereas growth in sediment (both DCR discharge and reference areas) was less than in eastern coal and taconite (western coal and limestone were similar to sediment).

One way of evaluating the influence of sediment chemistry on toxicity is to compare the concentrations of potentially toxic chemicals in the sediment to the survival of organisms in the toxicity tests. The comparison is based not on the absolute chemical concentration but rather the concentration compared to the level that is expected to cause an effect. For metals this is the probable effect concentration (PEC) quotient (MacDonald et al., 2000). For PAHs, this is the Equilibrium-partitioning Sediment Benchmark (ESB) (EPA, 2003). An exceedance of a PEC or an ESB greater than 1.0 is more likely to be associated with effects in benthic invertebrates. The mean PEC quotient is the average of all the ratios of chemical concentration to PEC value in a sediment sample. The ESB is the sum of all the ratios of individual PAH chemical concentrations, corrected for organic carbon content in the sediment, to chronic toxicity values, multiplied by a adjustment factor to account for PAHs that were not measured. Thus, a mean PEC quotient or ESB can be calculated for each sample tested toxicologically and compared to the toxicity test responses. In situations where toxicity is suspected, a higher mean PEC quotient or ESB should be negatively associated with toxicological response (e.g., lower survival). As shown in Figures 15 and 16, mean PEC quotients and ESBs do not appear to be associated with the toxicological responses.

Based on these results, it does not appear that chemical constituents in DCR discharge areas impact sediment chemistry. Sediment chemistry in DCR discharge and references areas is very similar, and concentrations of potentially toxic chemical may even be less in DCR discharge areas, and any observable difference in chemical composition is not likely to produce significant toxicity. While undiluted DCR discharge may produce toxicity from chemical exposure, under realistic dilution scenarios, the effects are similar to sediment in the effects are similar to effects in sediment from DCR discharge and reference areas. The overall reduced performance in toxicity testing (i.e., significant reductions in average organism growth and survival, as compared to the laboratory control) in DCR discharge and references area sediment is most likely not the result of chemical parameters.

Summary of Sediment Chemistry. The evaluation of sediment chemistry consisted of three independent analyses to produce three lines of evidence. For all three analyses, no impacts to sediment chemistry were anticipated. Some sediment toxicity was observed in DCR discharge areas when compared to reference areas, but the toxicity was not from DCR chemistry.

Biological Resources

The impacts on biological resources from DCR discharges, if any, result in changes in sediment or water quality. The measurement of the biological conditions should reflect the water and sediment quality and where changes in these characteristics from DCR discharge correlate with biological changes, the biological effects can be attributed to DCR. Two areas of biological resources (Special Status Species, and Protected and Sensitive Areas) are not addressed in this memorandum because no original data were collected in these areas as part of this program; however, they are addressed in the DEIS. Also, the impacts on invasive species are not addressed in this memo because the work in this area has not been completed.

Fish and Other Pelagic Organisms

Impacts to fish and other pelagic organisms found in the open water areas of the Great Lakes were evaluated by considering the same measures used to evaluate impacts to water quality, as described above, and by using the results of laboratory toxicity studies conducted with simulated slurries of DCR deck sweepings and sump material. The presence of an impact was determined if chemicals attributable to DCR were predicted to occur in the water column, even in the mixing zone, at concentrations greater than surface water quality criteria, if depletion of dissolved oxygen would occur from DCR, even in the mixing zone, and significant adverse effects were found on the survival or growth of test organisms exposed to simulated slurries of DCR or sump material. As described above, the discharge of DCR would not result in any exceedances of water quality criteria or impacts to dissolved oxygen. Thus from a water quality perspective no impact on biological resources is expected.

DCR slurry and sump liquids toxicity testing was conducted with the fathead minnow (*Pimephales promelas*) and the water flea (*Daphnia magna*) in acute bioassays (48 hours) with dilutions to conservatively simulate exposure to discharged slurries in the lake water column. Daphnid and minnow survival was decreased in undiluted sump slurry samples from a taconite vessel and a limestone vessel. Survival was not decreased in the other DCR sump liquid or deck-sweepings slurries. In the undiluted taconite sample slurry, aluminum, copper (total and dissolved), and zinc (total but not dissolved) concentrations exceeded acute criteria. In the undiluted limestone sample slurry, only aluminum exceeded criteria. In both samples, total iron also exceeded the chronic criterion (acute criterion are not available for iron). When these slurries were diluted to 1 percent, no effects on survival were observed.

Based on these results, no impacts to fish and other pelagic organisms are predicted.

Benthic Community

The benthic community comprises the interacting organisms found at or near the bottom of the Great Lakes and consists of organisms, such as worms, that generally reside in or on the upper portion of lake sediments or that spend a great deal of time in contact with lake sediments. Impacts to the benthic community were evaluated by comparing the benthic invertebrate community structure or composition within areas of high intensity DCR sweeping activities with the community structure in reference areas outside of the DCR discharge zones, by conducting bulk sediment toxicity with sediments from current DCR discharge zones and from reference areas, by comparing toxicity of DCR with toxicity of laboratory control sediments, and by comparing chemical tissue residues in benthic organisms in the DCR discharge zones with those of organisms from reference areas outside the DCR discharge zones.

Benthic Community Structure

Benthic community structure data were collected from the same sediment samples described above for chemical analysis (five shipping tracklines: two in Lake Superior, one in Lake Michigan, and two in Lake Erie). Each trackline consisted of a DCR discharge area and a reference area.

Data collected from Lake Superior do not suggest that the benthic community structure is impacted in DCR discharge areas relative to reference areas. Abundance (total number of organisms present and total number of organisms present within a specific taxonomic group) values were low in both DCR discharge and reference areas but similar to data collected by EPA (2007). Likewise, taxa richness (the number of taxonomic groups) was low, averaging 3 to 6 species per area, but within the range of 2 to 6 species per sample location observed by EPA (2007). The presence of the amphipod *Diporeia hoyi*, a sensitive species, in both reference and DCR discharge areas also suggests little, if any, impact.

The relationship between benthic community structure and DCR discharge areas in Lake Michigan is unclear. Metrics were both higher (abundance of freshwater clams [Family Sphaeriidae] and diversity [the number of taxa present and how evenly the density of organisms is partitioned among the taxa]) and lower (total organism abundance and aquatic worm abundance) in the DCR discharge area relative to the reference area. A comparison to EPA (2007) data suggests that taxa richness is within the previously measured range, but total organism abundance, observed at more than 2,000 organisms per square meter, was higher than that observed in this study (maximum of 759 per square meter). *Diporeia hoyi* was also observed at higher levels (fewer than 1,000 per square meter) by EPA (2007) as compared to this study (none observed). The results of this comparison suggest that impacts unrelated to DCR discharge are occurring throughout southern Lake Michigan, but further interpretation is limited by the small sample size.

The relationship between benthic community structure and DCR discharge areas in Lake Erie is unclear, but little difference was observed between areas. The benthic community structure in Lake Erie is influenced by many factors such as a high invasive mussel (Family Dreissenidae) population, which can significantly alter the lake bottom, and the eutrophic nature of the system, so it is difficult to differentiate relationships to DCR from other potential factors. EPA (2007) data for Lake Erie indicate high taxa richness (median of 11 taxa), high abundance (fewer than 6,000 organisms per square meter), no *Diporeia* spp., and where the amphipod was absent, aquatic worms were dominant. The results of this investigation in both tracklines and reference areas are consistent with EPA findings.

Further interpretation of the benthic community structure data is limited by the sample size, as well as by the potential for seasonal variations that could affect community structure. The accuracy in hitting acoustical anomalies in the DCR discharge areas increases the uncertainty in relating DCR discharge to changes in benthic community structure. Based on visual observations, the greatest amount of DCR was observed in the Lake Superior (Duluth) DCR discharge area replicate sample 3 (LS2-SD-T2-03) and Lake Erie (Cleveland) DCR discharge area replicate sample 2 (LE2-SD-T2-02). Benthic community data in LS2-SD-T2-03 are within the range of samples for DCR discharge and reference area samples for all metrics. A large number of dreissenids were observed in LE2-SD-T2-02, as well as more gastropods and chironomids and fewer oligochaetes, suggesting possible community shifts with a large amount of DCR.

Maher (1999) performed an extensive evaluation of benthic community structure in Lake Ontario and observed differences in the composition of species found in DCR discharge areas compared to reference areas. Three mechanisms were proposed for this community shift: physical disturbance, contaminant effects, and coarsening and de-enrichment of sediment. Physical disturbance would be the result of addition of DCR to the substrate that leads to an increase of early colonizing species. Contaminant effects may affect the species composition and affect the permeability of sediments. A coarsening and de-enrichment of the sediment would affect those species with grain size and organic content preferences. In this study, we found little evidence for differences in chemistry between DCR discharge areas and reference areas that would result in contaminant effects, but a coarsening and de-enrichment mechanism is possible as we found noticeable grain size differences that may be attributable to DCR. The results of our study do not suggest a physical disturbance mechanism, but our results are limited by the small sample size and limited number of taxa collected, as compared to Maher (1999).

Based on the results of this investigation and previous studies, DCR discharge has the potential to produce changes in the benthic community. However, these changes cannot be easily predicted, as they may be the result of several mechanisms and interactions with other factors, such as a high invasive mussel population and the eutrophic nature of some systems. The shift in community structure is not considered impairment and may only be short term, as Soster and McCall (1990) and McCall and Soster (1990) have found that successional stages in Lake Erie were not obvious after 2–14 months, and is therefore considered insignificant.

Toxicity Testing

As discussed above, toxicity testing was performed on sediment collected from DCR discharge areas using sediment testing organisms, *Hyallela azteca* and *Chironomus dilutus*. Figures 11 through 14 present the results of the sediment toxicity testing, with reference lines showing average responses from DCR toxicity testing for comparison. Although results from both DCR discharge areas and reference areas were significantly less than the laboratory control for many samples, there were only a few differences between the DCR discharge area and the reference areas, and the effects observed do not appear to be associated with any chemical constituent.

Sediments in DCR discharge and references areas are very similar chemically, and concentrations of potentially toxic chemicals may be even less in DCR discharge areas. Thus, difference in chemical composition is not likely to be the cause of differences in toxicity. Whereas undiluted DCR discharge may produce toxicity from chemical exposure, under realistic dilution scenarios, the effects are similar to sediment in DCR discharge areas. The overall reduced performance (i.e., significant reductions from the laboratory control) in DCR discharge and references area sediment is most likely the result of a combination of chemical contribution from sources other than DCR and physical parameters that are not readily distinguishable.

Benthic Tissue

Benthic tissue was collected in DCR discharge and reference areas and analyzed chemically. Due to equipment malfunctions that resulted in a small tissue volume collected, a complete chemical analysis was not possible for all samples. Interpretation of these data are also limited because individual benthic species were not separated (a composite sample was required to obtain sufficient volume) or depurated prior to analysis, and only a limited number of samples were collected (a second sampling trip was undertaken to collect additional tissue samples from the DCR discharge and reference areas). Based on this limited data, it appears that chemicals in the tissue of benthic organisms from DCR discharge areas are at levels similar to those in the tissue of benthic organisms from reference areas (see Table 10). PAHs are slightly higher in the tissue collected from the Lake Michigan DCR discharge area as compared to the reference area, but sediment PAH concentrations appear elevated throughout southern Lake Michigan, with the highest concentrations observed in the reference area.

Waterfowl

Some species of waterfowl feed on benthic organisms at water depths that could potentially expose them to chemicals in DCR or to chemicals that have accumulated in the tissue of benthic organisms within DCR discharges areas.

Impacts to waterfowl were estimated with a food web model and benthic tissue data. For modeling purposes, the long-tailed duck (*Clangula hyemalis*) was used as a representative species that may forage in DCR discharge and reference areas. The long-tailed duck is a small duck that can submerge to deep depths, winters in the Great Lakes, and eats primarily invertebrates, such as amphipods, mollusks, and oligochaetes, as well as fish. Long-tailed duck food web exposure to chemicals in benthic tissue was estimated using the following formula (modified from EPA [1993]):

$$DI_x = \frac{[[\sum_i (FIR)(FC_{xi})(PDF_i)] + [(FIR)(SC_x)(PDS)])]]}{BW}$$

where:

DI_x	=	Dietary intake for chemical *x* (mg chemical/kg body weight/day)
FIR	=	Food ingestion rate (kg/day, dry weight)
FC_{xi}	=	Concentration of chemical *x* in food item *i* (mg/kg, dry weight)
PDF_i	=	Proportion of diet composed of food item *i* (dry weight basis)
SC_x	=	Concentration of chemical *x* in sediment (mg/kg, dry weight)
PDS	=	Proportion of diet composed of sediment from incidental ingestion (dry weight basis)
BW	=	Body weight (kg, wet weight)

Conservative values (i.e., ones that over predict impacts) specific to the long-tailed duck that were used as input variables to this equation were obtained from the scientific literature. Consistent with a conservative approach, a minimum body weight and maximum food ingestion rate were used. To account for incidental ingestion of sediment while foraging, the maximum sediment concentration in each area was also used. In addition, it was assumed that chemicals are 100 percent bioavailable and it was assumed that the duck spends 100 percent of its time feeding in the DCR discharge or reference areas. Dietary exposure estimates were derived for each bioaccumulative chemical as defined by EPA (2000). An example calculation for arsenic is presented in Table 8.

Exposure levels associated with negative effects were developed for each chemical. Toxicological information from the literature for wildlife species most closely related to waterfowl were used, when available, but was supplemented by laboratory studies of nonwildlife species (e.g., chickens) when necessary. The ingestion screening values are expressed as milligrams of the chemical per kilogram body weight of the receptor per day (mg/kg-BW/day). Growth and reproduction were emphasized as assessment endpoints because they are the most ecologically relevant to maintaining viable populations and because they are generally the most studied chronic toxicological endpoints for ecological receptors. If several chronic toxicity studies were available from the literature, the most appropriate study was selected for each receptor species based upon study design, study methodology, study duration, study endpoint, and test species. No observed adverse effect levels (NOAELs) based on growth and reproduction were used, when available, as the primary screening values. Since a chronic NOAEL was unavailable for antimony, a NOAEL estimate was extrapolated from a chronic lowest observed adverse effect level (LOAEL) using an uncertainty factor of 10. Ingestion screening values for are summarized in Table 9.

The estimated exposure concentrations or doses from each benthic tissue sample and sediment were divided by the NOAEL effects levels in Table 9 to derive hazard quotients. An example of this calculation for arsenic is also presented in Table 8. Hazard quotients exceeding one indicate the potential for risk because the constituent concentration or dose (exposure) exceeds the effects level. However, as described above, the exposure estimates and effects levels are derived using intentionally conservative assumptions such that hazard quotients greater than or equal to one do not necessarily indicate that risks are present or impacts are occurring. Rather, it identifies constituent-pathway-receptor combinations that may require further evaluation. Hazard quotients that are less than 1 indicate that risks are very unlikely, enabling a conclusion of no significant elevated risk to be reached with high confidence.

The results of the hazard quotient calculations for each benthic tissue chemical and sample analyzed are presented in Table 10. All hazard quotients were less than 1.0, except chromium in the Lake Michigan reference sample and benzo(a)pyrene, benzo(b)fluoranthene, and chrysene in the Lake Michigan DCR discharge area. However, the food web exposures in these samples only slightly exceeded the effects levels, as all hazard quotients were less than 2.0, suggesting that even with conservative assumptions, impacts are unlikely. If less conservative assumptions were used, such as an average body weight or ingestion rate or a less-conservative effects level (in the Lake Michigan DCR discharge, hazard quotients based on the LOAL would be less than 0.2), the hazard quotients would not exceed 1.0. More importantly, because chemical constituents in sediment and benthic tissue from DCR discharge areas are similar to that in reference areas, the potential impacts from DCR discharge to waterfowl appear negligible.

The food web model analysis only evaluates ingestion through the food web, and does not consider potential impacts from the gathering of grit, which can occur at deep depths. In addition to the long-tailed duck, common loons may dive to deep depths and have been recorded at depths up to 600 feet in the Great Lakes (Ehrlich et al. 19888). Franson et al. (2001) described the dimension of stones found in the stomach of dead loons. Stones retained in sieves with mesh sizes between 4.75 mm and 8.00 mm accounted for the greatest percentage (by mass) of grit in loon stomachs. Although coal, limestone, and taconite collected from cargo vessels was predominantly within the range of 0.6 to 1.18 mm, it is possible that DCR discharge will contain particles of this size. However, sediment collected in DCR discharge areas typically had almost no particles in the size range. As discussed above the chemical concentrations of DCR is lower than that of existing sediments, even if waterfowl ingest individual DCR particles no chemical effects would occur.

Summary of Impacts

The impacts from past and ongoing DCR practices to segments of the ecosystem potentially influenced by the discharge of DCR are summarized in Table 11. The potential impacts in this analysis (no impact, insignificant impact, or significant impact) are associated with the DEIS alternative of continuing the existing IEP. The results will also be used to predict impacts of alternative methods of managing DCR evaluated in the DEIS.

For water quality, no impacts to water chemistry (including toxicity), dissolved oxygen, or nutrient enrichment are predicted, with little uncertainty because any effects are diminished at dilutions expected from DCR discharges (i.e., at least 27,000 to 1).

For sediment quality, no impacts from sediment deposition rate or to sediment chemistry, which consisted of three independent analyses, are predicted. Some sediment toxicity was observed in DCR discharge areas when compared to reference areas, but the toxicity does not appear to be associated with any chemical constituent. Impacts to sediment physical structure, defined as noticeable grain size differences among sediments from DCR discharge areas, may occur in at least some areas of intense DCR discharge, but these impacts are likely insignificant because the increased heterogeneous grain size distribution provides increased habitat diversity relative to that of reference areas.

For biological resources, no impacts to fish and other pelagic organisms are predicted. DCR discharge has the potential to produce changes in the benthic community because of changes to the sediment physical structure. However, these changes are not easily predicted, as they may be the result of several mechanisms and interactions with other factors. The shift in community structure is not considered impairment and may only be short term, and is therefore considered insignificant. Impacts to waterfowl, either through the foodweb or from grit ingestion, are not predicted.

References

Alaska Department of Environmental Conservation (Commercial Passenger Vessel Environmental Compliance Program). 2001. *Cruise Ship Wastewater Science Advisory Panel Report to the Alaska Cruise Ship Initiative – Near Field Dispersion of Wastewater behind a Moving Large Cruise Ship*. June.

Beyer WN, Connor EE, Gerould S. 1994. Estimates of soil ingestion by wildlife. *Journal of Wildlife Management.* 58:375-382.

CH2M HILL. 2007a. *USCG Dry Cargo Sweepings Scientific Investigation: Sweepings Characterization – Chemical Analyses*. Prepared for the U.S. Coast Guard.

CH2M HILL. 2007b. *USCG Dry Cargo Sweepings Scientific Investigation: Sweepings Characterization – Toxicological Analyses*. Prepared for the U.S. Coast Guard.

CH2M HILL. 2007c. *USCG Dry Cargo Sweepings Scientific Investigation: Biological Characterization – Nutrient Enrichment*. Prepared for the U.S. Coast Guard.

CH2M HILL. 2007d. *USCG Dry Cargo Sweepings Scientific Investigation: Identification of Sonar Investigation Sites.* Prepared for the U.S. Coast Guard.

CH2M HILL. 2007e. *Dry Cargo Residue Discharge Analysis for the U.S. Coast Guard*. Technical Memorandum. Prepared for the U.S. Coast Guard.

CH2M HILL. 2007f. *USCG Dry Cargo Residue Spring 2007 Scientific Investigation: Depositional Area Characterization*. Prepared for the U.S. Coast Guard.

Clyne MV. 2000. *The Effects of Ship-Derived Wastes on Metal Contents of Lake Ontario Sediment*. M.S. thesis presented to the Graduate School at State University of New York at Stony Brook. 89 pp.

Ehrlich P, Bobkins DS, Wheye D. 1988. *The Birder's Handbook: A Field Guide to the Natural History of North American Birds*. Simon & Shuster Publishing. 785 pp.

EPA. 1993. *Wildlife Exposure Factors Handbook*. Volume I of II. EPA/600/R-93/187a.

EPA. 1997. *Mercury study report to Congress. Volume VI: an ecological assessment of anthropogenic mercury emissions in the United States.* EPA/452/R-97/008.

EPA. 1999. *Screening level ecological risk assessment protocol for hazardous waste combustion facilities.* EPA/530/D-99/001A. Peer Review Draft. August.

EPA. 2000. *Methods for Measuring the Toxicity and Bioaccumulation of Sediment-associated Contaminants with Freshwater Invertebrates.* Second Edition. EPA/600-R-99/064. Method 100.5.

EPA. 2003. *Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures*. EPA/600/R-02/013.

EPA. 2007. *Great Lakes Monitoring*. U.S. Environmental Protection Web site. Available at http://www.epa.gov/glnpo/monitor.html. Accessed June, 2007.

Franson CJ, Hansen SP, Pokras MA, Miconi R. 2001. Size characteristics of stones ingested by common loons. *Condor*. 103(1)189-191.

Great Lakes & Seaway Shipping Online Fleet Photo Gallery History and Photos of Great Lakes Vessels. 2007. Available at http://www.boatnerd.com. Accessed on May, 2007.

Habitat Solutions. 2006. *Great Lakes Dry Cargo Sweepings Impact Analysis: Side-scan Sonar Data Acquisition Report.* Prepared for Volpe National Transportation System Center, Parsons Brinckerhoff Quade & Douglas, Inc., and CH2M HILL.

Loehr L, Atkinson CM, George K, Beegle-Krause CJ. 2003. Using a simple dilution model to estimate wastewater contaminant concentrations behind moving passenger vessels. *Oceans 2003 Proceedings.* Volume 1, pp. 390–93.

MacDonald DD., Ingersoll CG, Berger TA. 2000. Development and evaluation of consensus-based sediment quality guidelines. *Archives of Environmental Contamination and Toxicology*. 39:20-31.

Maher NP. 1999. *Effects of Cargo Sweeping Deposits on Benthic Community Structure in the Shipping Lanes of Western Lake Ontario*. M.S. thesis presented to the Graduate School at State University of New York at Stony Brook. 115 pp.

McCall PL, Soster FM. 1990. Benthos response to disturbance in western Lake Erie – regional faunal surveys. *Canadian Journal of Fisheries and Aquatic Sciences*. 47(10):1996-2009.

Mudroch A, Sarazin L, Lomas T. 1988. Summary of surface and background concentrations of selected elements in the Great Lakes sediments. *Journal of Great Lakes Research*. 14(2):241-251.

Reid DF, Meadows GA. 1999. *Proceedings of the Workshop: The Environmental Implications of Cargo Sweepings in the Great Lakes*. National Oceanic and Atmospheric Administration (NOAA) Technical Memorandum ERL GLERL-114. NOAA Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan, USA. 66 pp.

Rigdon RH, Neal J. 1963. Fluorescence of chickens and eggs following the feeding of benzpyrene crystals. *Texas Reports on Biology and Medicine*. 21(4):558-566.

Robertson GJ, Savard JPL. 2002. Long-tailed Duck (*Clangula hyemalis*). In: *The Birds of North America*, No. 651 (A. Poole and F. Gill, eds.). The Birds of North America, Inc., Philadelphia, PA.

Sample BE, Opresko DM, Suter II GW. 1996. *Toxicological benchmarks for wildlife: 1996 revision*. Environmental Restoration Division, ORNL Environmental Restoration Program. ES/ER/TM-86/R3.

Soster FM, McCall PL. 1990. Benthos response to disturbance in western Lake Erie – field experiments. *Canadian Journal of Fisheries and Aquatic Sciences*. 47(10):1970-1985.

U.S. Coast Guard. 2002. "A Study of Dry Cargo Residue Discharges in the Great Lakes." Prepared for the U.S. Coast Guard, Office of Operating and Environmental Standards (G-MSO), Environmental Standards Division (G-MSO-4). Washington, D.C.

U.S. Coast Guard. 2005. *Study of Incidental Dry Cargo Residue Discharges in the Great Lakes*. Prepared for the U.S. Coast Guard, Office of Standards Evaluation and Development (G-PSR-1), Washington, D.C.

Volpe National Transportation System Center, Parsons Brinckerhoff Quade & Douglas, Inc., and CH2M HILL. 2006a. *Scientific Approach for Dry Cargo Sweepings Impact Analysis*. Prepared for the U.S. Coast Guard, Washington, D.C.

Volpe National Transportation System Center, Parsons Brinckerhoff Quade & Douglas, Inc., and CH2M HILL. 2006b. *Scientific Plan for Dry Cargo Sweepings Impact Analysis*. Prepared for the U.S. Coast Guard, Washington, D.C.

TABLE 1
Relative Quantities of Dry Cargo Types

	1997 to 2001 Cargo (PMG, 2002)	**2001 Discharge (PMG, 2002)**	**1998 to 2004 Cargo (e^2M, 2005)**	**2004 Discharge (e^2M, 2005)**
Iron ore	39.7%	36.9%	50.7%	58.8%
Coal	23.4%	27.0%	21.2%	19.7%
Limestone	22.1%	26.0%	26.5%	20.5%
Combined Iron Ore, Coal, and Limestone	***84.1%***	***89.9%***	***98.3%***	***99.1%***
Salt	4.3%	2.1%	0.9%	NR
Grain	8.9%	2.3%	0.3%	NR
Coke	NR	1.5%	NR	NR
Cement/Gypsum	3.1%	0.3%	NR	NR
Millscale	NR	0.1%	NR	NR
Slag	NR	0.9%	NR	NR
Cement	NR	0.5%	NR	NR
Sand	NR	0.2%	NR	NR
Potash	0.4%	0.2%	NR	NR

NR= not reported due to insufficient volume for analysis

TABLE 2
Modeling Results (Water Quality)

DCR Sweepings Material	Taconite		Coal		
	Deck	Sump	Coal (Deck)	Coal (Sump)	Limestone Deck (a)
Mass of DCR discharge (lb)	233	–	150	–	270
Volume of discharge (gallons)	9,087	4,000	6,450	4,000	7,560
Duration of discharge (s)	600	600	600	600	600
Vessel speed (knots)	12	12	12	12	12
Vessel width (ft)	68	68	68	68	68
Vessel draft (ft)	10	10	10	10	10
Distance of discharge (ft)	12,152	12,152	12,152	12,152	12,152
Rate of DCR discharge (gpm)	909	400	645	400	756
Estimated dilution factor	27,000:1	62,000:1	38,000:1	62,000:1	33,000:1

(a) Dilution was not calculted for limestone sump because no compound in the limestone slurry exceed water quality criteria thus it was not necessary to apply a dilution factor to determine compliance.

TABLE 3
Exceedance Ratios

Analyte	Chronic Water Quality Criteria	Taconite		Easter Coal		Western Coal		Limestone	
		Deck	Sump	Deck	Sump	Deck	Sump	Deck	Sump
Aluminum	0.75 mg/L	—	—	—	—	—	11	—	10.9
Benzo(a)anthracene	0.027 µg/L	—	—	—	—	—	**3.4**	—	—
Benzo(a)pyrene	0.014 µg/L	—	—	—	—	—	**2.6**	—	—
Cadmium	0.00025 mg/L	—	**2.7**	—	—	—	—	—	**8**
Cadmium, dissolved	0.00021 mg/L	—	**1.8**	—	—	—	—	—	**7.2**
Chrysene	0.014 µg/L	—	—	**3.2**	—	—	**7.1**	—	—
Copper	0.009 mg/L	—	2.9	—	—	—	—	—	1.5
Copper, dissolved	0.009 mg/L	—	2.2	—	—	—	—	—	**1.4**
Fluorene		—	—	—	—	—	—	—	—
Iron	1 mg/L	**1.3**	**6.2**	—	—	—	**9.8**	—	**1.6**
Lead	0.003 mg/L	—	**2.3**	—	—	—	—	—	**2.5**
Lead, dissolved	0.003 mg/L	—	**1.2**	—	—	—	—	—	**1.2**
Pyrene	0.014 ug/l	—	—	**3.2**	—	**3.2**	**31.4**	—	—
Selenium	0.005 mg/L	—	—	—	—	—	—	—	**1.9**
Selenium, dissolved	0.005 mg/L	—	—	—	—	—	—	—	**2.4**
Zinc	0.12 mg/L	—	**1.2**	—	—	—	—	—	**1.6**

Note: Bold numbers also exceed acute water quality criteria.

TABLE 4
Nutrient Concentrations in Simulated DCR Slurry and Lake Water

	NO_3 (mg/L)		TKN (mg/L)		TN (mg/L)		TP (mg/L)	
	Lake Water	Simulated Slurry	Lake Water	Simulated Slurry	Lake Water	Simulated Slurry	Lake Water	Simulated Slurry
Iron								
Lake Superior	—	—	—	—	—	—	0.02	0.03
Lake Erie	—	—	—	—	—	—	—	—
Eastern Coal								
Lake Superior	—	—	—	—	—	—	—	—
Lake Erie	—	—	—	—	—	—	—	—
Western Coal								
Lake Superior	0.36	0.37	—	—	—	—	—	—
Lake Erie	—	—	0.85	1.26	0.99	1.43	0.02	0.13
Limestone								
Lake Superior	0.37	0.38	—	—	—	—	—	—
Lake Erie	—	—	—	—	—	—	—	—

Shaded cells indicate values are statistically different
Nutrients with no statistical difference are not shown

TABLE 5

Natural and DCR Deposition Rates (a)

	Range of Natural Deposotion Rates (g/m²/yr)		Typical Range in Track Line (g/m²/yr)	Maximum DCR Deposition Rates (g/m²/yr) (b)
	Lower End	Upper End		
Erie	180	10000	2300	0.72
Michigan	20	2500	490	0.65
Superior	25	3040	50	0.06
Ontario	85	1225	490	0.05

(a) Taken from discussions of sedimentation rates in Dry Cargo Residue Discharge Analysis for the U.S. Coast Guard Technical Memorandum (CH2M HILL, 2007e) and DEIS Chpater 3.

(b) Maximum total DCR deposition rate calculated for most intense shipping in Potomac Study (PMG, 2002).

TABLE 6

Maximum Sediment Concentrations (mg/kg) in DCR Discharge and Reference Areas, with Screening Guidelines and the Ranges of Values

		Lake Superior					Lake Michigan			Lake Erie				
Analyte	**Sediment Guideline Value (MacDonald et**	**LS1**	**LS1-Ref**	**LS2**	**LS-2-Ref**	**Mudroch et al., 1988**	**LM1**	**LM1-Ref**	**Mudroch et al., 1988**	**LE1**	**LE1-Ref**	**LE2**	**LE2-Ref**	**Mudroch et al., 1988**
Arsenic	9.79	18.6	20.5	51.4	28.6	Not Available	14.4	11.1	5.0–15.0	5.09	7.42	13.2	9.8	0.45–12.3
Cadmium	0.99	2.15	2.05	2.84	2.82	1.4–2.5	2.32	1.52	0.05–1.8	3.08	2.53	2.72	2.22	0.8–13.7
Chromium	43.4	61.5	52	46.2	43.6	29.5–60.2	49.4	39.9	140	53.7	52.7	68.2	60.6	12–362
Copper	31.6	128	134	81.6	83.5	113–173	49.9	36.7	54	47.1	46.6	56.3	48.6	5–207
Iron	Not Available	53,200	52,700	64,700	50,900	49,100–57,600	29,400	23,300	Not Available	33,700	35,000	44,600	49,300	11,000–77,900
Lead	35.8	63.5	69.5	44.7	50.3	74.9–138	112	65.2	10–130	47.7	46.1	64.7	52.7	6–299
Mercury	0.18	0.135	0.134	0.117	0.127	0.094–0.16	0.11	0.0942	0.030–0.380	0.352	0.399	0.17	0.208	0.045–4.8
Nickel	22.7	45.5	41	44.5	42.2	28.9–66.4	51.3	29.9	25	50.3	51	67.2	58	16–150
Zinc	121	166	174	140	145	143-195	190	143	40–350	180	180	214	240	18–536

TABLE 7

Comparison of Inorganic Concentrations in DCR and Sediment from Previous Investigations

DCR Type	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Nickel (mg/kg)	Zinc (mg/kg)
CH2M HILL (2007a)					
Coal Deck Sweepings	10.65	17.13	5.98	10.45	28.88
Coal SS	9.9	14.8	2.67	4.56	15.8
Limestone Deck Sweepings	3.33	2.87	7.78	5.12	8.82
Limestone SS	5.69	4.32	1.12	9.73	23.38
Taconite Deck Sweepings	10.15	2.83	0.93	2.68	6.07
Taconite SS	9.34	4.28	4.11	3.55	30.51
Clyne (2000)					
Average Non-impacted DCR Discharge Areas	81.29	119.71	91.43	98.86	303.71
Average Impacted DCR Discharge Areas	65	105	70	91.5	264

TABLE 8
Example Food Web Calculation for Waterfowl

$$DI_x = \frac{[\sum(FIR)(FC_{xi})(PDF_i) + [(FIR)(SC_x)(PDS)]}{BW}$$

$$HQ = \frac{DI_x}{\text{Screening Value}}$$

Symbol	Value	Description	Units
DI_x	Calculated	Dietary intake for constituent x (arsenic)	mg chemical/kg body weight/day
FIR	6.19E-02	Food ingestion rate based allometric equation for wading birds (EPA, 1993) and using the maximum reported body weight of 1.1 kg for the long-tailed duck (Robertson and Savard, 2002)	kg/day (dry weight)
FC_{xi}	1.79E-01	Concentration of analyte x (arsenic) in aquatic invertebrates (benthic tissue composite)	mg/kg (dry weight)
PDF_i	9.67E-01	Proportion of diet composed of aquatic invertebrates (assumed)	(dry weight)
SC_x	51.4	Maximum concentration of analyte x (arsenic) in sediment in area	mg/kg (dry weight)
PDS	3.30E-02	Proportion of diet composed of sediment. Based on value for mallard from Beyer et al. (1994)	(dry weight)
BW	5.00E-01	Minimum long-tailed duck body weight (Robertson and Savard, 2002)	kg (wet weight)

DI_x = 0.23

NOAEL Screening Value (from Table 8) = 5.14

HQ (see Table 10) = 0.045

TABLE 9
Waterfowl Ingestion Screening Values

Analyte	Test Organism	Duration	Exposure Route	Effect/Endpoint	NOAEL (mg/kg/d)		LOAEL (mg/kg/d)		Reference
Inorganics									
Arsenic	mallard	128 days	oral in diet	survival	5.14E+00		1.28E+01		Sample et al., 1996
Cadmium	mallard	90 days	oral in diet	reproduction	1.45E+00		2.00E+01		Sample et al., 1996
Chromium	black duck	10 months	oral in diet	reproduction	1.00E+00		5.00E+00		Sample et al., 1996
Copper	chicks	10 weeks	oral in diet	growth/survival	4.70E+01		6.17E+01		Sample et al., 1996
Lead	quail	12 weeks	oral in diet	reproduction	1.13E+00		1.13E+01		Sample et al., 1996
Mercury	mallard	3 generations	oral in diet	reproduction	2.60E-02		7.80E-02		EPA, 1997
Nickel	mallard	90 days	oral in diet	growth/survival	7.74E+01		1.07E+02		Sample et al., 1996
Selenium	mallard	100 days	oral in diet	reproduction	4.00E-01		8.00E-01		Sample et al., 1996
Silver	mallard	14 days	oral in diet	survival	1.78E+01	(b)	1.78E+02	(a)	EPA, 1999
Zinc	chicken	44 weeks	oral in diet	reproduction	1.45E+01		1.31E+02		Sample et al. 1996
Polyaromatic Hydrocarbons									
Acenaphthene	chicken	35 days	oral in diet	reproduction	7.10E+00	(b)	7.10E+01	(a)	Rigdon and Neal, 1963
Acenaphthylene	chicken	35 days	oral in diet	reproduction	7.10E+00	(b)	7.10E+01	(a)	Rigdon and Neal, 1963
Anthracene	chicken	35 days	oral in diet	reproduction	7.10E+00	(b)	7.10E+01	(a)	Rigdon and Neal, 1963
Benzo(a)anthracene	chicken	35 days	oral in diet	reproduction	7.10E+00	(b)	7.10E+01	(a)	Rigdon and Neal, 1963
Benzo(a)pyrene	chicken	35 days	oral in diet	reproduction	7.10E+00	(b)	7.10E+01	(a)	Rigdon and Neal, 1963
Benzo(b)fluoranthene	chicken	35 days	oral in diet	reproduction	7.10E+00	(b)	7.10E+01	(a)	Rigdon and Neal, 1963
Benzo(g,h,i)perylene	chicken	35 days	oral in diet	reproduction	7.10E+00	(b)	7.10E+01	(a)	Rigdon and Neal, 1963
Benzo(k)fluoranthene	chicken	35 days	oral in diet	reproduction	7.10E+00	(b)	7.10E+01	(a)	Rigdon and Neal, 1963
Chrysene	chicken	35 days	oral in diet	reproduction	7.10E+00	(b)	7.10E+01	(a)	Rigdon and Neal, 1963
Dibenz(a,h)anthracene	chicken	35 days	oral in diet	reproduction	7.10E+00	(b)	7.10E+01	(a)	Rigdon and Neal, 1963
Fluoranthene	chicken	35 days	oral in diet	reproduction	7.10E+00	(b)	7.10E+01	(a)	Rigdon and Neal, 1963
Fluorene	chicken	35 days	oral in diet	reproduction	7.10E+00	(b)	7.10E+01	(a)	Rigdon and Neal, 1963
Indeno(1,2,3-cd)pyrene	chicken	35 days	oral in diet	reproduction	7.10E+00	(b)	7.10E+01	(a)	Rigdon and Neal, 1963
Phenanthrene	chicken	35 days	oral in diet	reproduction	7.10E+00	(b)	7.10E+01	(a)	Rigdon and Neal, 1963
Pyrene	chicken	35 days	oral in diet	reproduction	7.10E+00	(b)	7.10E+01	(a)	Rigdon and Neal, 1963

(a) Uncertainty factor of 10 applied for conversion between NOAEL and LOAEL
(b) Acute or subchronic to chronic uncertainty factor of 10 applied

TABLE 10
Waterfowl Foodweb Modeling Results

	LS2-TS-Sled			LE1-TS-SLED			LM2-TS-RSLED-01			LM2-TS-RSLED-02			LE2-TS-SLED			RFI-TS-SLED		
Analyte	**Maximum Sediment (mg/kg)**	**Benthic Tissue Composite (mg/kg dry)**	**Hazard Quotient**	**Maximum Sediment (mg/kg)**	**Benthic Tissue Composite (mg/kg dry)**	**Hazard Quotient**	**Maximum Sediment (mg/kg)**	**Benthic Tissue Composite (mg/kg dry)**	**Hazard Quotient**	**Maximum Sediment (mg/kg)**	**Benthic Tissue Composite (mg/kg dry)**	**Hazard Quotient**	**Maximum Sediment (mg/kg)**	**Benthic Tissue Composite (mg/kg dry)**	**Hazard Quotient**	**Maximum Sediment (mg/kg)**	**Benthic Tissue Composite (mg/kg dry)**	**Hazard Quotient**
Inorganics																		
Arsenic	51.4	0.179	0.045	5.03	0.866	0.024	14.4	0.994	0.035	11.1	2.58	0.069	13.2	0.863	0.031	7.42	0.589	0.020
Cadmium	2.84	0.0552	0.013	3.08	1.48	0.13	2.32	0.613	0.057	1.52	0.612	0.055	2.72	0.616	0.059	2.53	1.11	0.10
Chromium	46.2	0.235	0.22	53.7	3.99	0.70	49.4	3.17	0.58	39.9	10.3	1.40	68.2	2.17	0.54	52.7	3.04	0.58
Copper	81.6	11.3	0.036	47.1	9.43	0.028	49.9	10.3	0.031	36.7	8.39	0.025	56.3	6.55	0.022	46.6	10.2	0.030
Lead	44.7	0.0736	0.17	47.7	3.49	0.54	112	3.4	0.77	65.2	2.99	0.55	64.7	1.69	0.41	46.1	3.27	0.51
Mercury	0.117	0.01	0.064	0.352	0.0266	0.18	0.11	0.0104	0.07	0.0942	0.0232	0.12	0.17	0.0099	0.072	0.399	0.0206	0.16
Nickel	44.5	0.253	0.0027	50.3	3.81	0.009	51.3	5.84	0.01	29.9	3.58	0.007	67.2	2.04	0.0067	51	2.99	0.007
Selenium	1.56	0.102	0.046	*1.48*	0.619	0.20	2.14	0.903	0.29	*4.39*	0.93	0.32	*1.98*	0.464	0.16	1.45	0.372	0.13
Silver	0.704	0.167	0.0013	0.828	0.165	0.0013	*0.742*	0.163	0.0013	*0.802*	0.17	0.0013	*0.926*	0.165	0.0013	0.825	0.167	0.0013
Zinc	140	4.92	0.08	180	16.8	0.19	190	13.2	0.16	143	30.8	0.29	214	18.7	0.21	180	21.6	0.23
Polyaromatic Hydrocarbons																		
Acenaphthene	0.006	6.7	0.11	0.0045	2	0.034	0.014	6.7	0.11	0.02	6.7	0.11	0.0092	2.9	0.049			
Acenaphthylene	0.0078	3.3	0.056	0.016	1	0.017	0.012	16	0.27	0.02	3.3	0.056	0.02	1.4	0.024			
Anthracene	0.019	4.1	0.069	0.017	1	0.017	0.04	23	0.39	0.06	3.3	0.056	0.027	1.5	0.025			
Benzo(a)anthracene	0.065	6.7	0.11	0.074	2	0.034	0.13	46	0.78	0.16	14	0.24	0.1	4.4	0.074			
Benzo(a)pyrene	0.064	6.7	0.11	0.093	3.8	0.064	0.15	85	1.43	0.17	36	0.61	0.13	9.5	0.16			
Benzo(b)fluoranthene	0.12	13	0.22	0.17	4	0.068	0.25	89	1.50	0.28	28	0.47	0.26	12	0.20			
Benzo(g,h,i)perylene	0.053	10	0.17	0.087	3	0.051	0.13	57	0.96	0.14	22	0.37	0.12	4.3	0.073			
Benzo(k)fluoranthene	0.042	10	0.17	0.068	3	0.051	0.11	41	0.69	0.10	8.9	0.15	0.11	4.4	0.074			
Chrysene	0.077	4.5	0.076	0.13	4	0.068	0.18	67	1.13	0.21	20	0.34	0.18	11	0.19			
Dibenz(a,h)anthracene	0.015	10	0.17	0.023	3	0.051	0.033	19	0.32	0.038	7.4	0.12	0.03	4.3	0.073			
Fluoranthene	0.13	8.1	0.14	0.17	4.8	0.081	0.3	57	0.96	0.39	15	0.25	0.21	11	0.19			
Fluorene	0.009	6.7	0.11	0.014	2	0.034	0.018	6.7	0.11	0.027	6.7	0.11	0.016	2.9	0.049			
Indeno(1,2,3-cd)pyrene	0.051	10	0.17	0.078	3	0.051	0.12	53	0.89	0.13	17	0.29	0.11	5.9	0.10			
Phenanthrene	0.08	12	0.20	0.065	5.5	0.093	0.19	25	0.42	0.21	20	0.34	0.11	15	0.25			
Pyrene	0.11	6.7	0.11	0.16	2.8	0.047	0.27	58	0.98	0.30	19	0.32	0.21	4.7	0.079			

Blank cells indicate chemical analysis not performed
Shaded cells indicate Hazard Quotients greater than or equal to 1.0
Results in italics indicate analyte was not detected
LS2-TS-Sled = Lake Superior (Duluth) DCR Discharge Area
LM2-TS-RSLED-01 = Lake Michigan (2nd Trip) - DCR Discharge Area
LM2-TS-RSLED-02 = Lake Michigan (2nd Trip) - Reference Area
LE2-TS-Sled = Lake Erie (Cleveland) DCR Discharge Area
RFI-TS-SLED = Lake Erie Reference Area

TABLE 11
Summary of DCR Impact Analysis

Resource Area	DEIS Alternative: Continue the Existing IEP
Water Quality	
Water Chemistry	No Impact
Nutrient Enrichment	No Impact
Dissolved Oxygen	No Impact
Sediment Quality	
DCR Deposition Rate	No Impact
Physical Habitat Changes	Insignificant Impact
Sediment Chemistry	No Impact
Biological Resources	
Special Status Species	NA
Protected and Sensitive Areas	NA
Fish and Other Pelagic Organisms	No Impact
Benthic Community Structure	Insignificant Impact
Invasive Species	NA
Waterfowl	No Impact

NA = Not evaluated in this memorandum

= No Impact

= Insignificant Impact

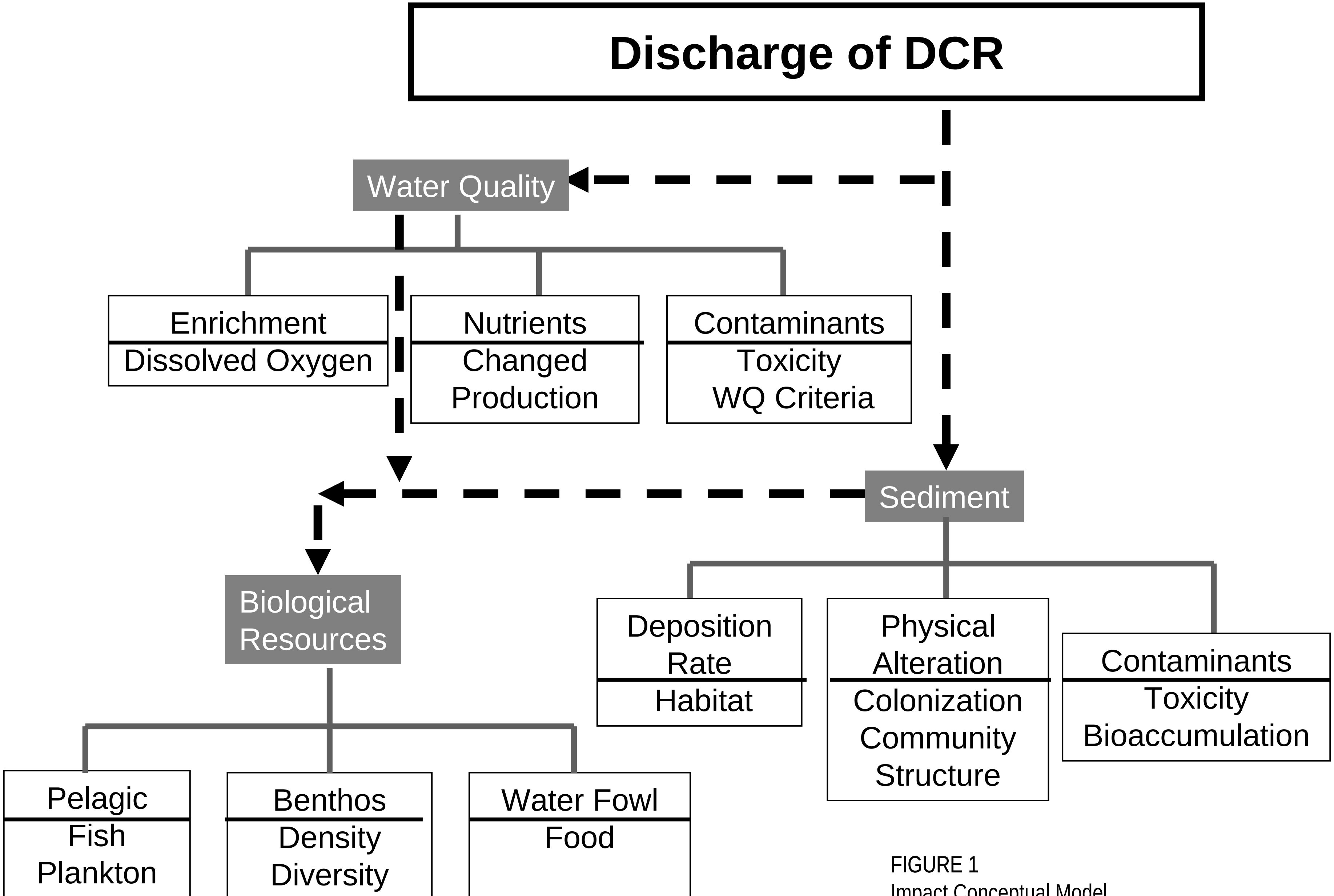

FIGURE 1
Impact Conceptual Model

	Areas of Potential Impact						
Scientific Investigations	Water Chemistry	Enrichment & Nutrients	Sediment Chemistry	Sediment Alteration & Deposition	Benthos	Pelagic Organisms	Water Fowl
Sweepings Characterization							
Sweepings Discharge Analysis							
Historic Deposition Analysis							
Physical Characterization of Deposition Area							
Chemical Characterization of Deposition Area							
Toxicity Tests							
Benthic Community Structure							
Nutrient Enrichment							

FIGURE 2
Scientific Investigation of Impacts: Multiple Lines of Evidence

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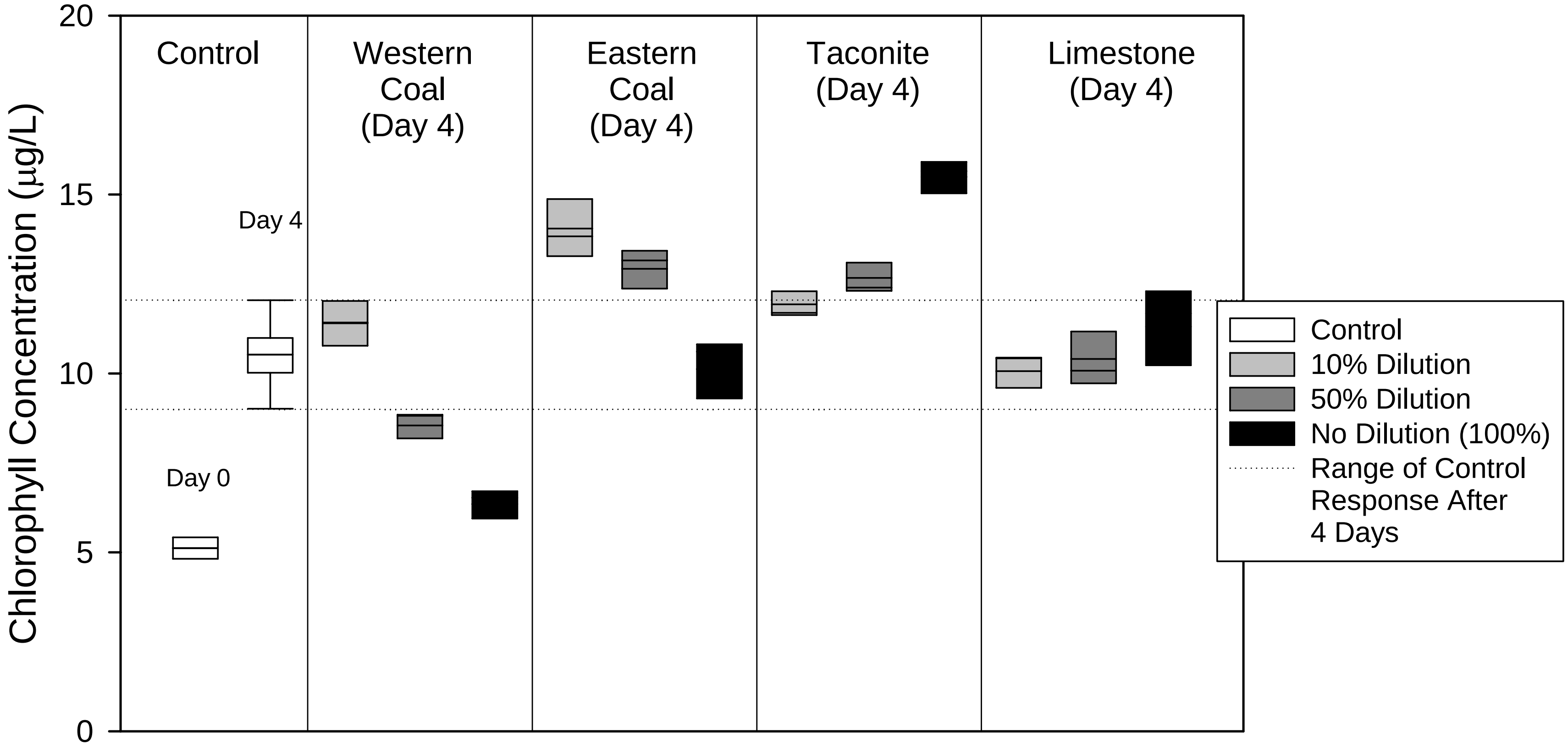

FIGURE 3
Aquatic Plant Stimulation
in Lake Erie

CH2MHILL

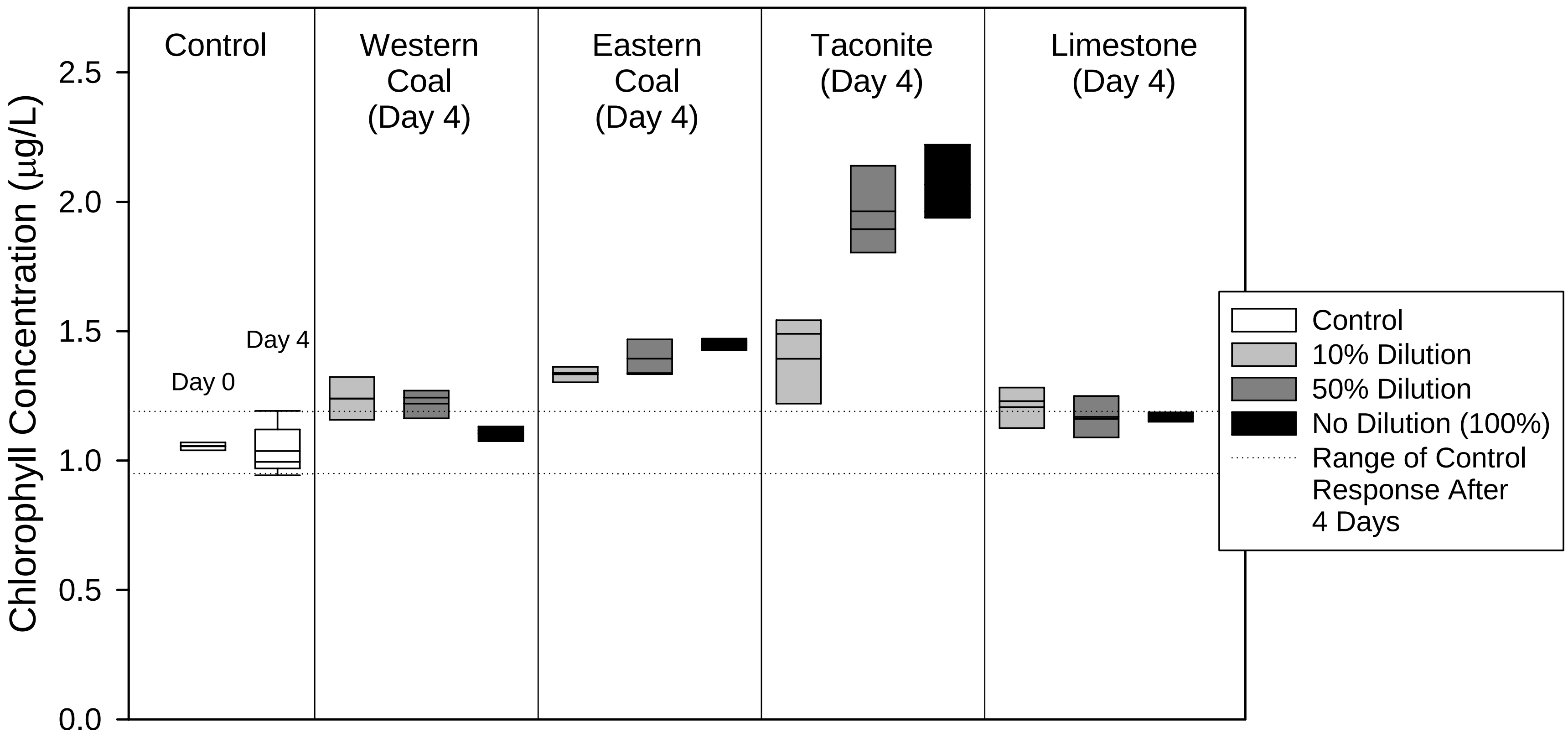

FIGURE 4
Aquatic Plant Stimulation
in Lake Superior

CH2MHILL

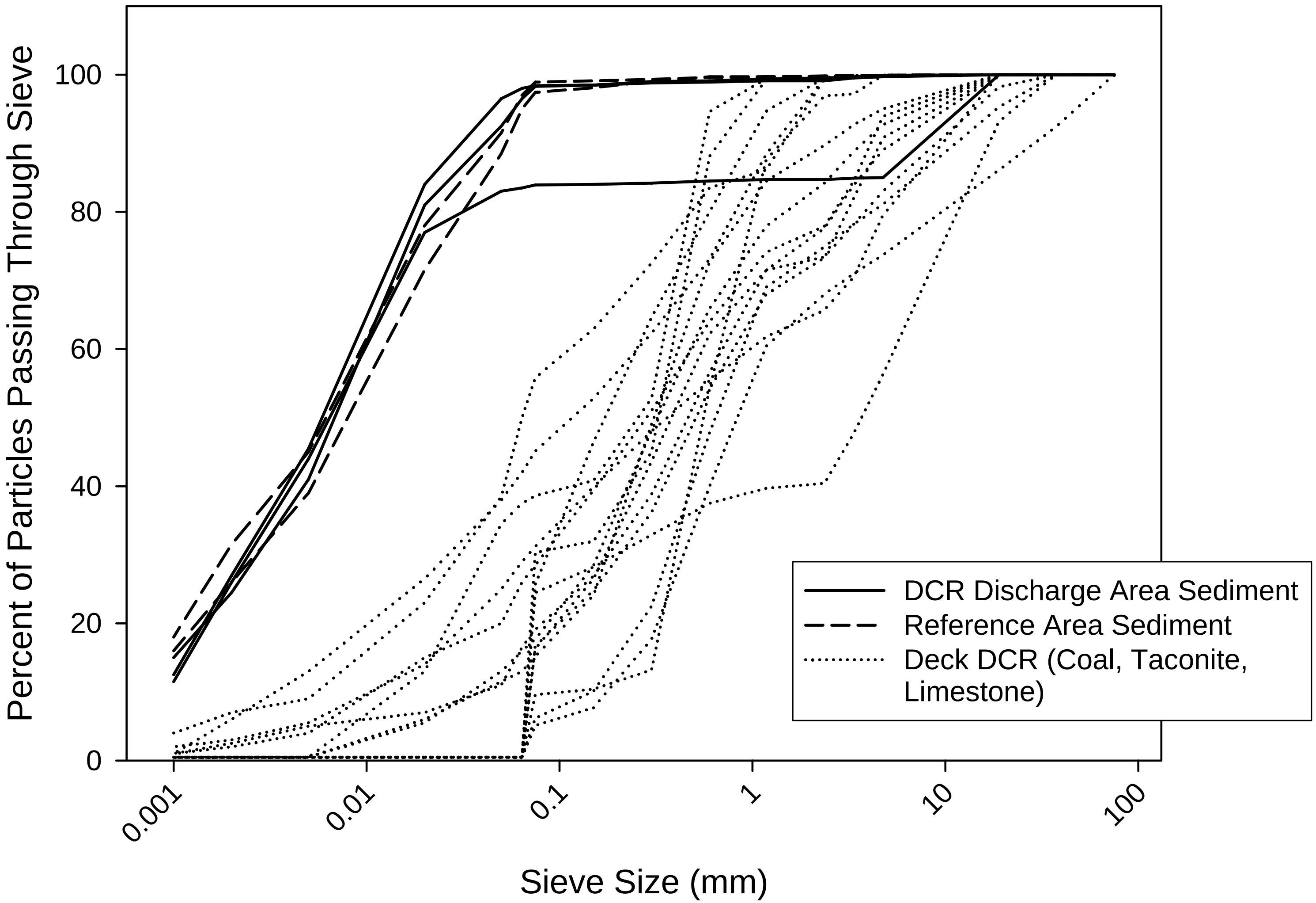

FIGURE 5
Lake Superior (Silver Bay) Sediment and DCR Grain Size

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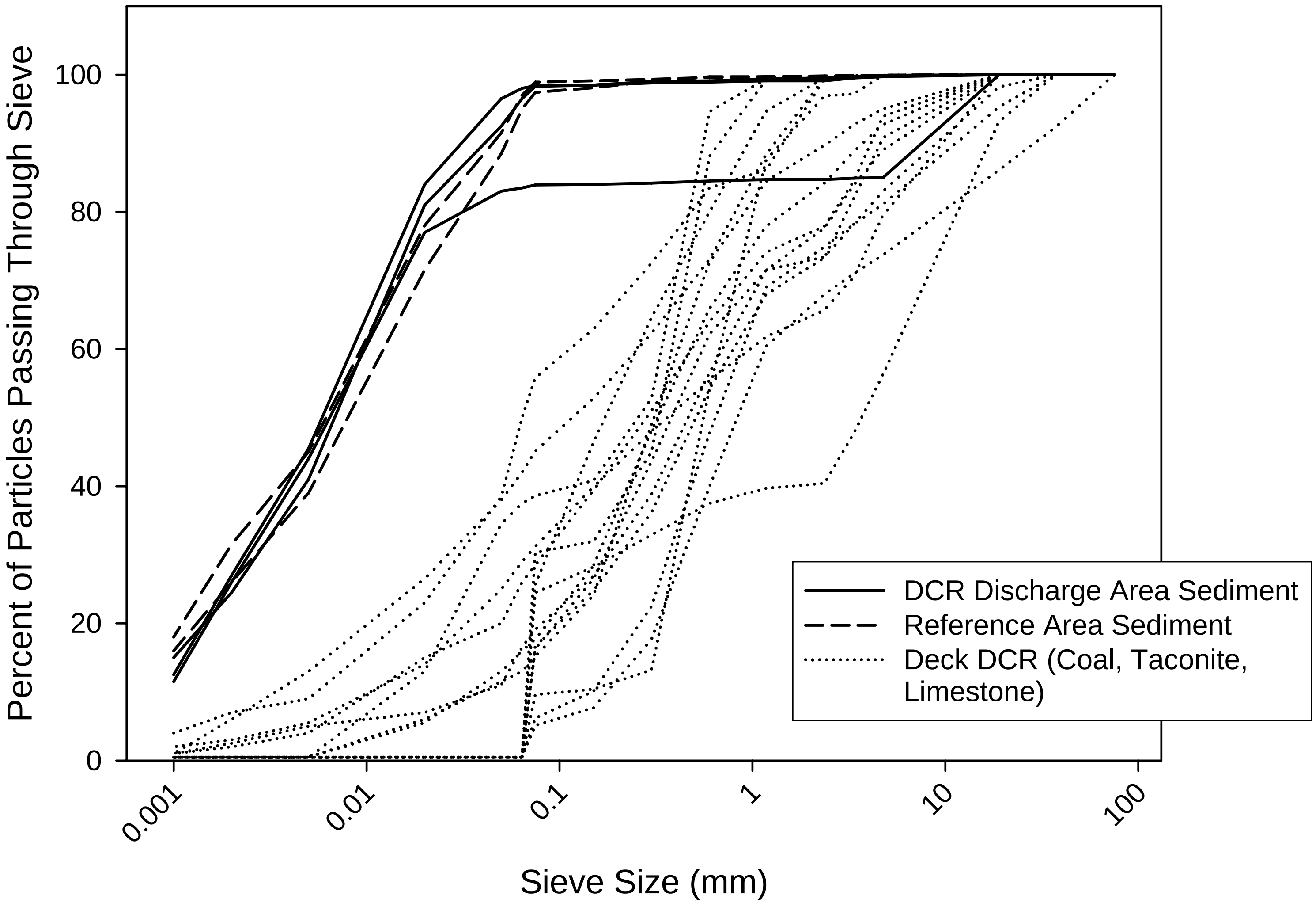

FIGURE 6
Lake Superior (Duluth) Sediment and DCR Grain Size

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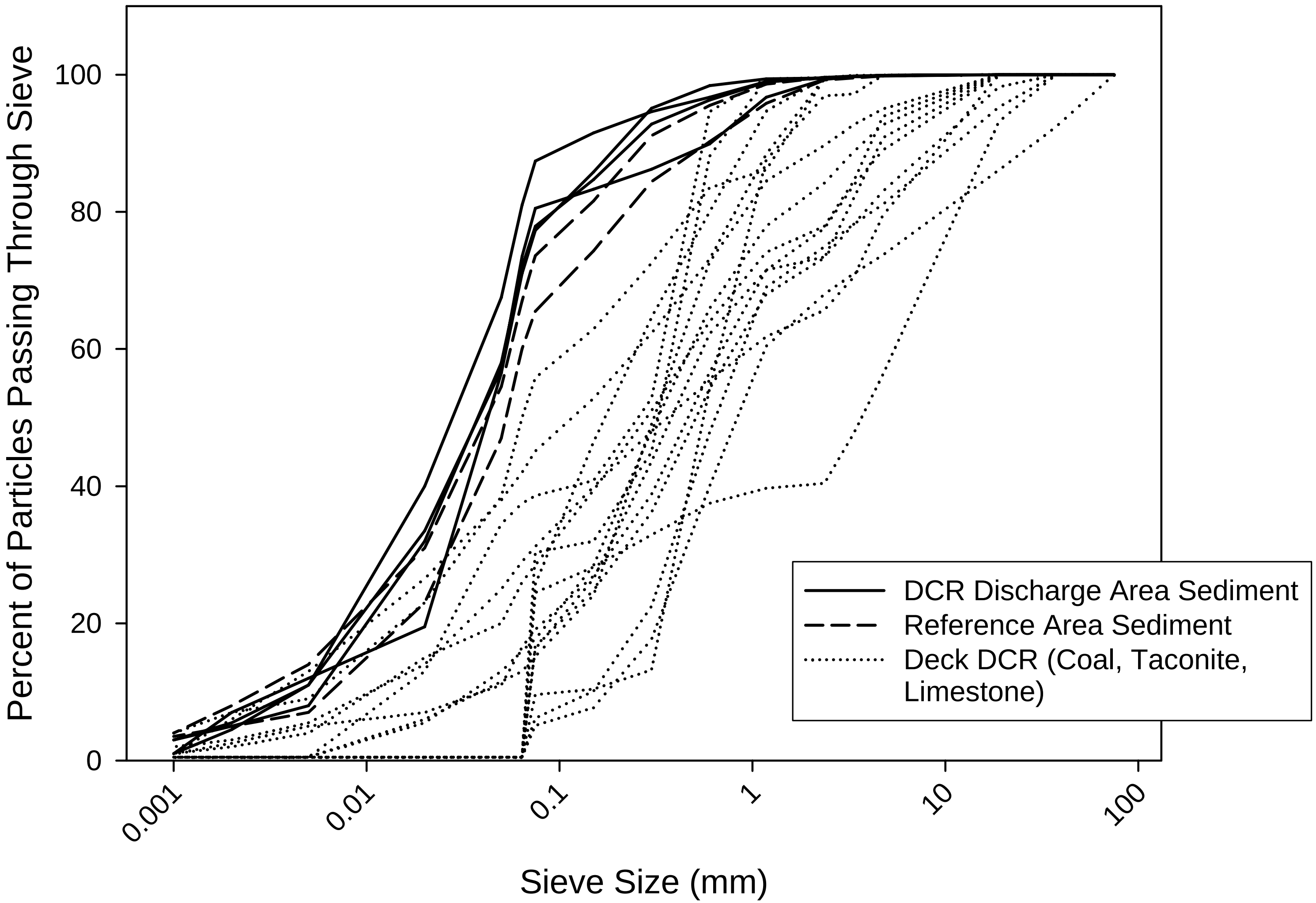

FIGURE 7
Lake Michigan Sediment
and DCR Grain Size

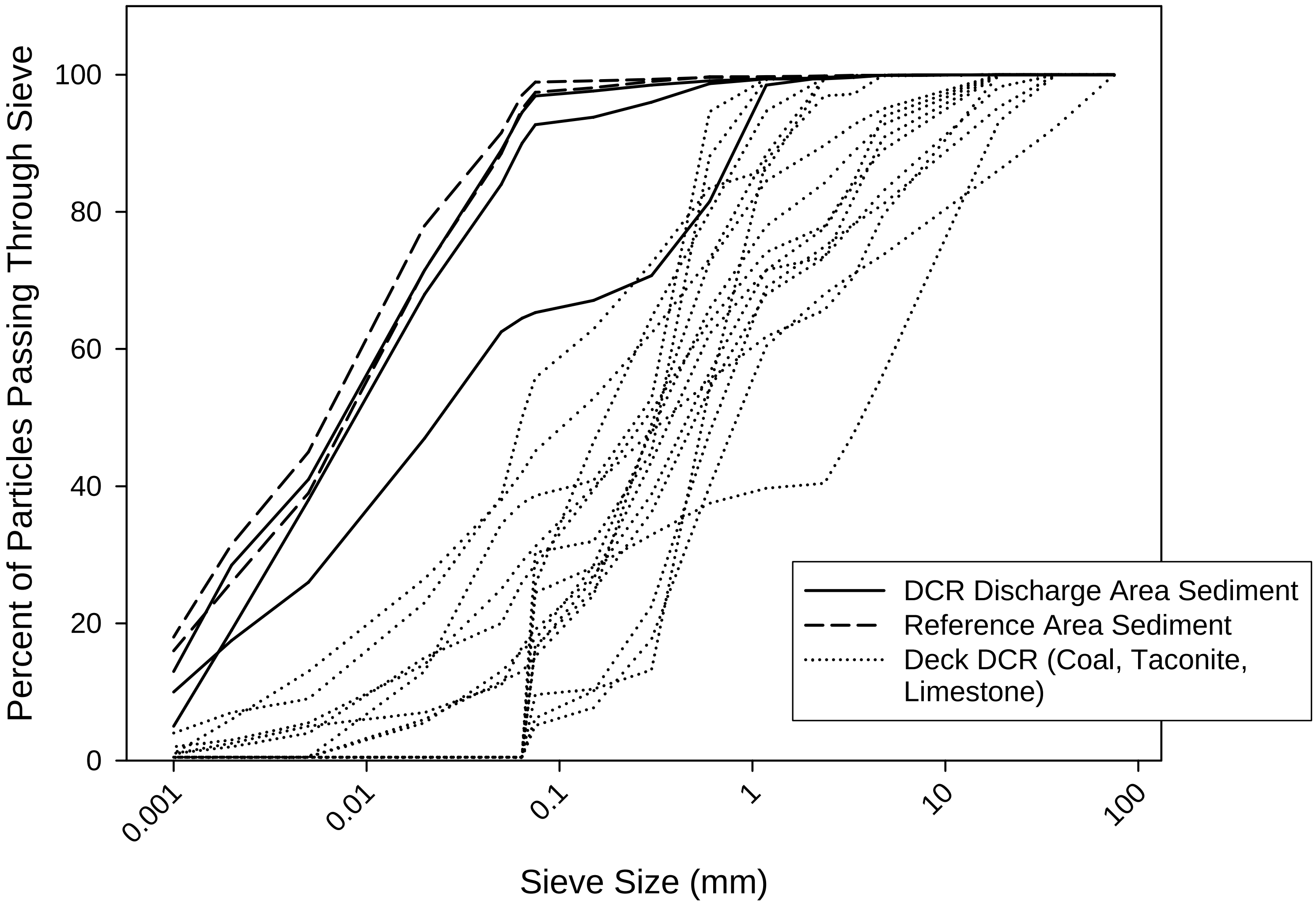

FIGURE 8
Lake Erie (Marblehead)
Sediment and DCR Grain
Size

CH2MHILL

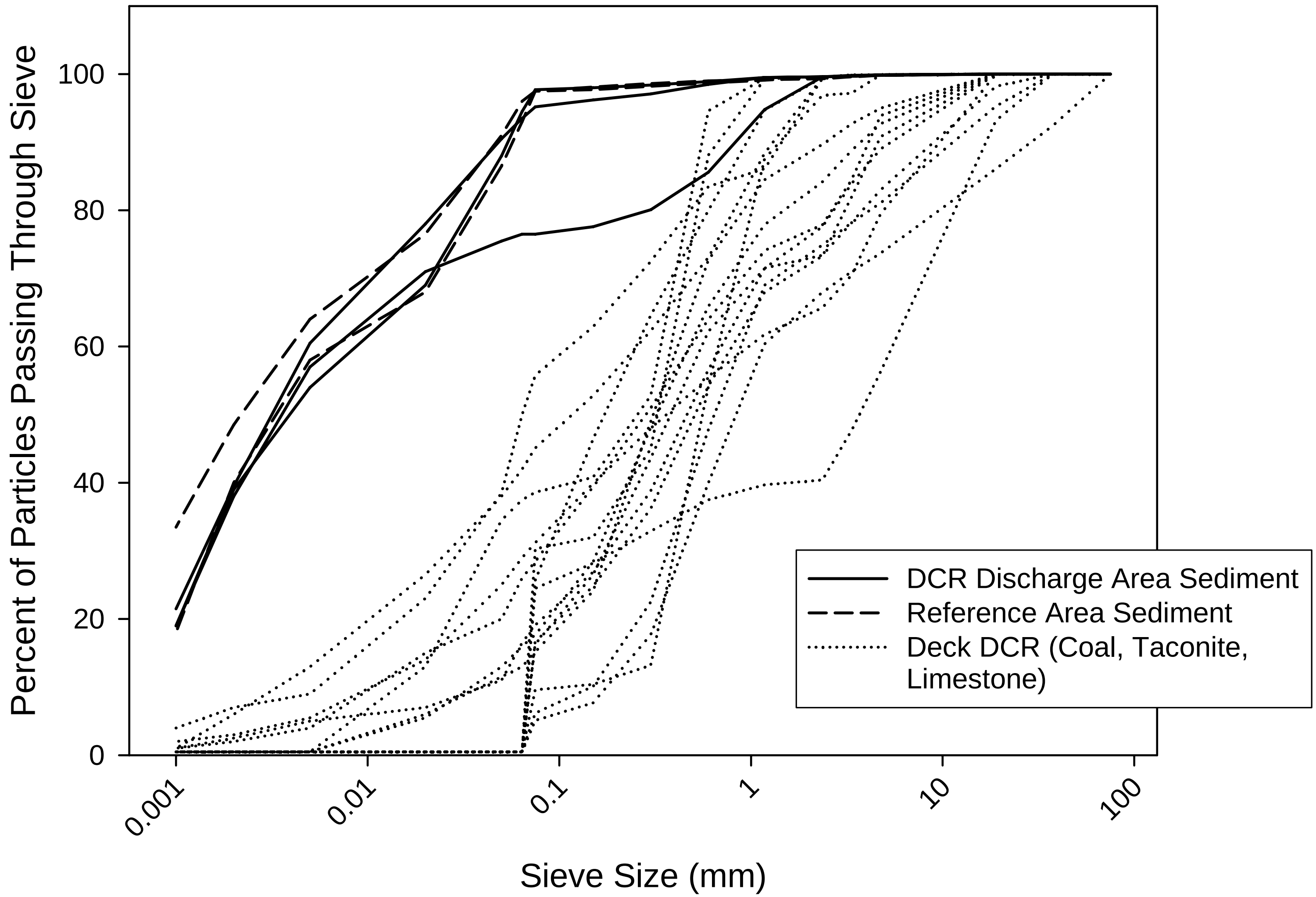

FIGURE 9
Lake Erie (Cleveland)
Sediment and DCR Grain
Size

CH2MHILL

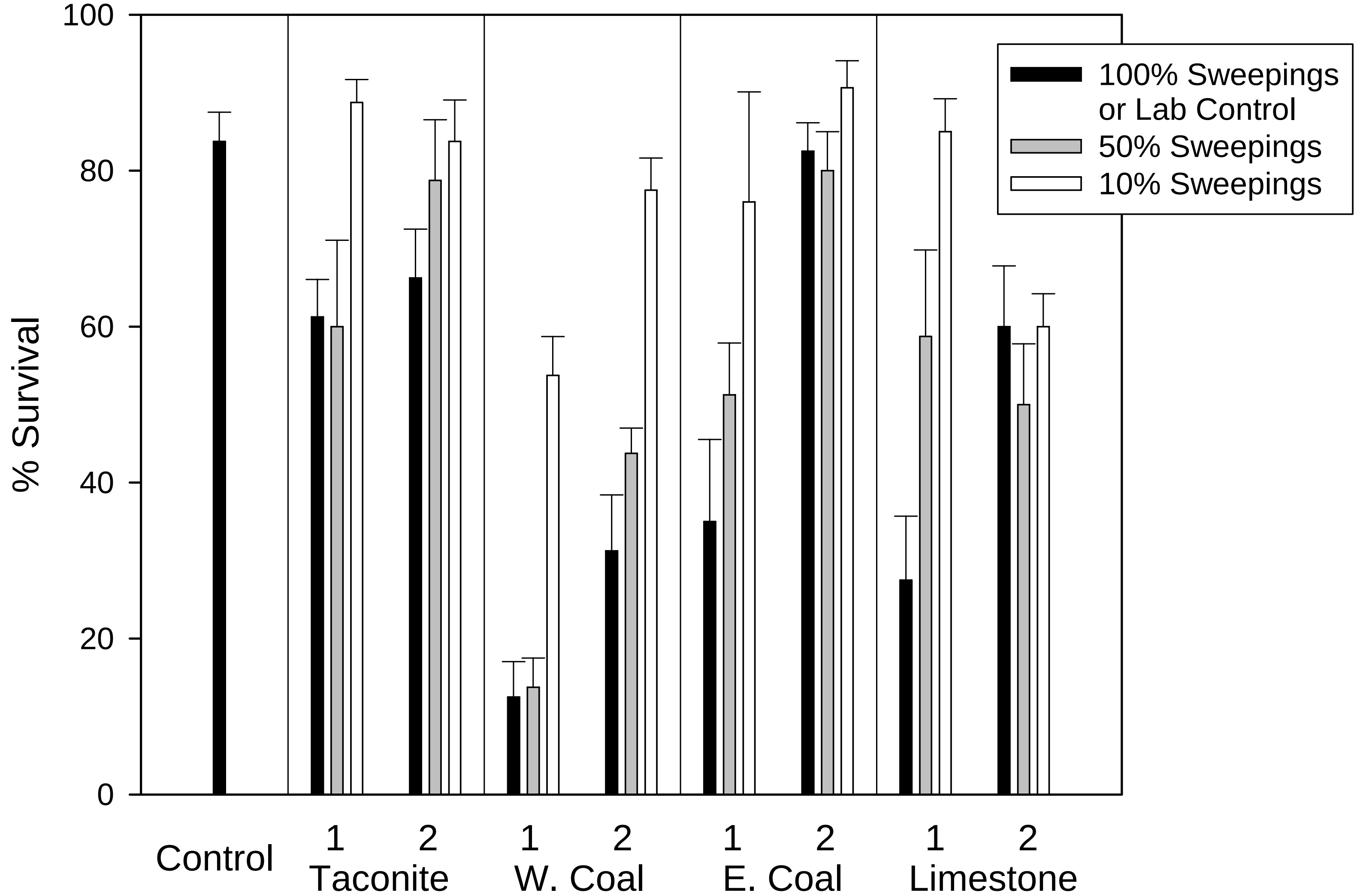

FIGURE 10
Hyallela azteca Survival in
DCR with Dilutions

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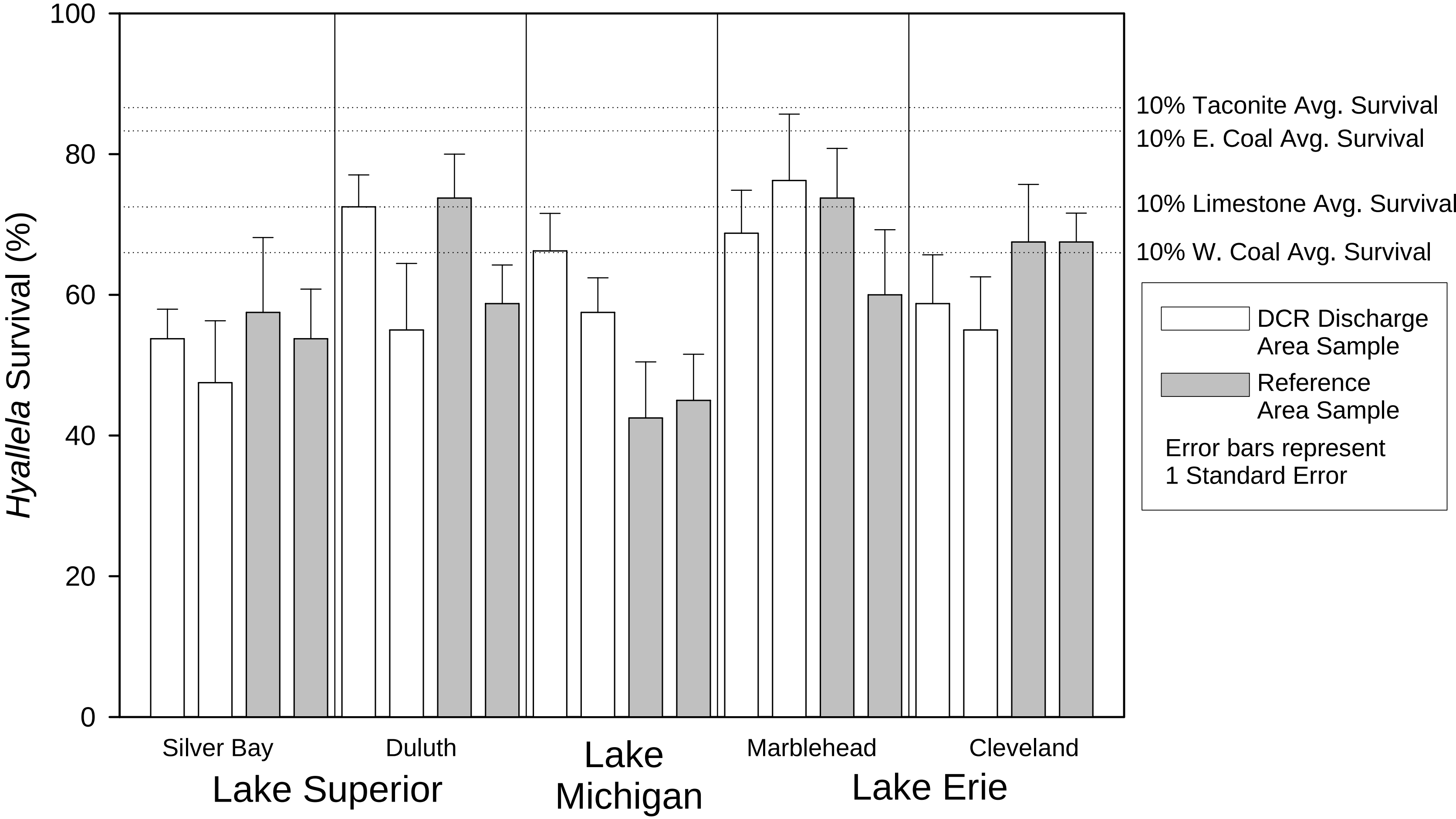

FIGURE 11
Hyallela azteca Survival in DCR Discharge and Reference Areas

CH2MHILL

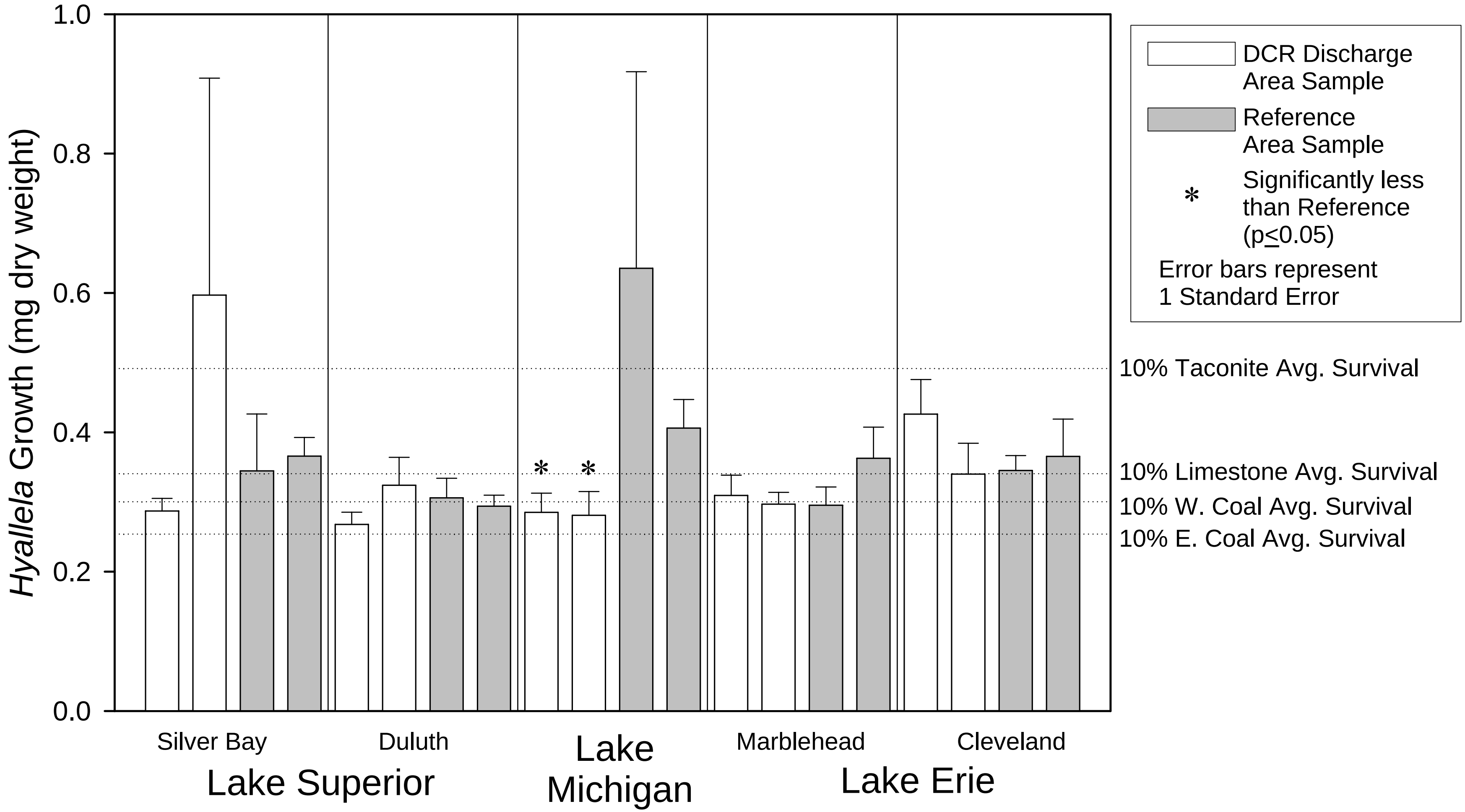

FIGURE 12
Hyallela azteca Growth in DCR Discharge and Reference Areas

CH2MHILL

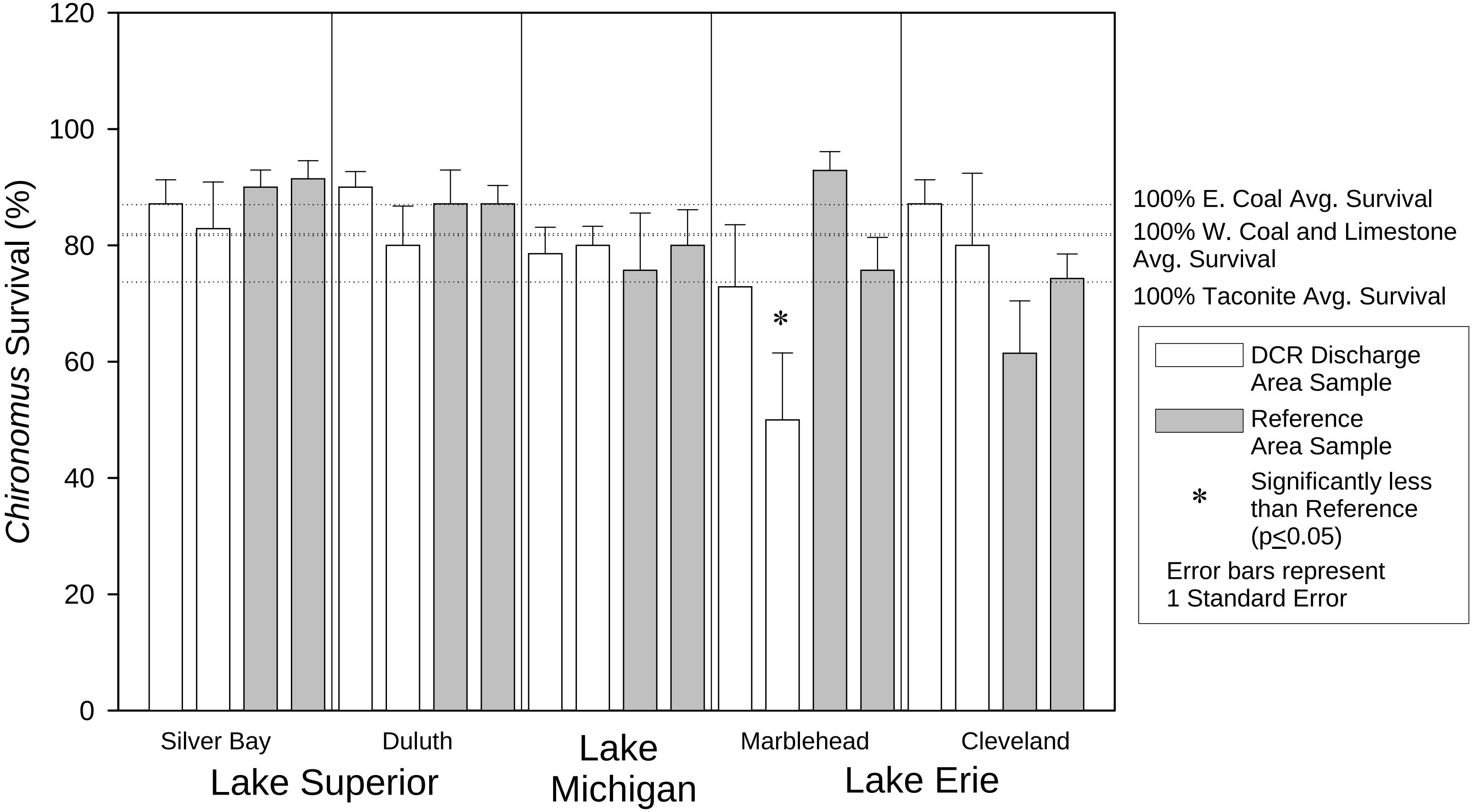

FIGURE 13
Chironomus dilutus
Survival in DCR discharge
and Reference Areas

CH2MHILL

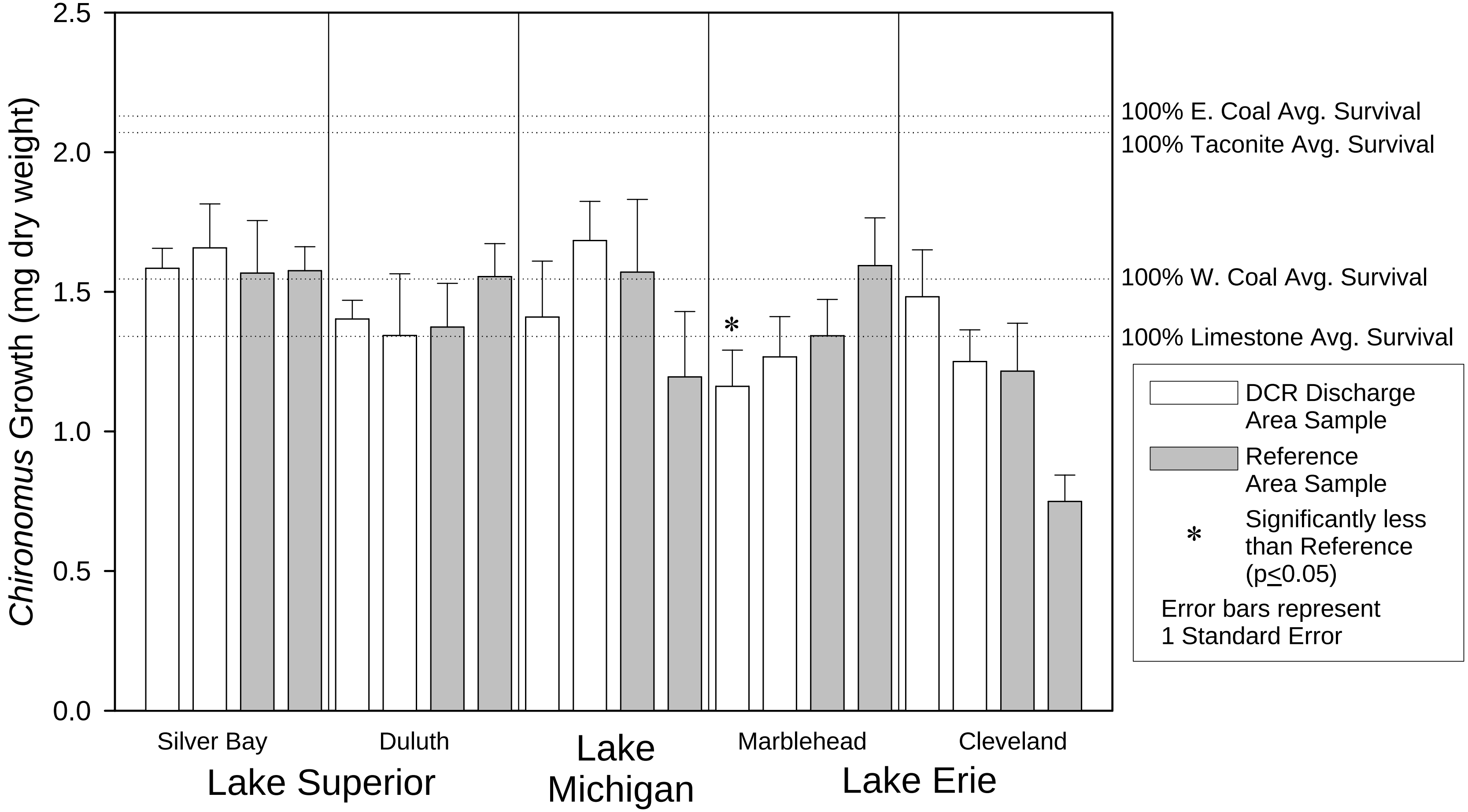

FIGURE 14
Chironomus dilutus
Growth in DCR Discharge
and Reference Areas

CH2MHILL

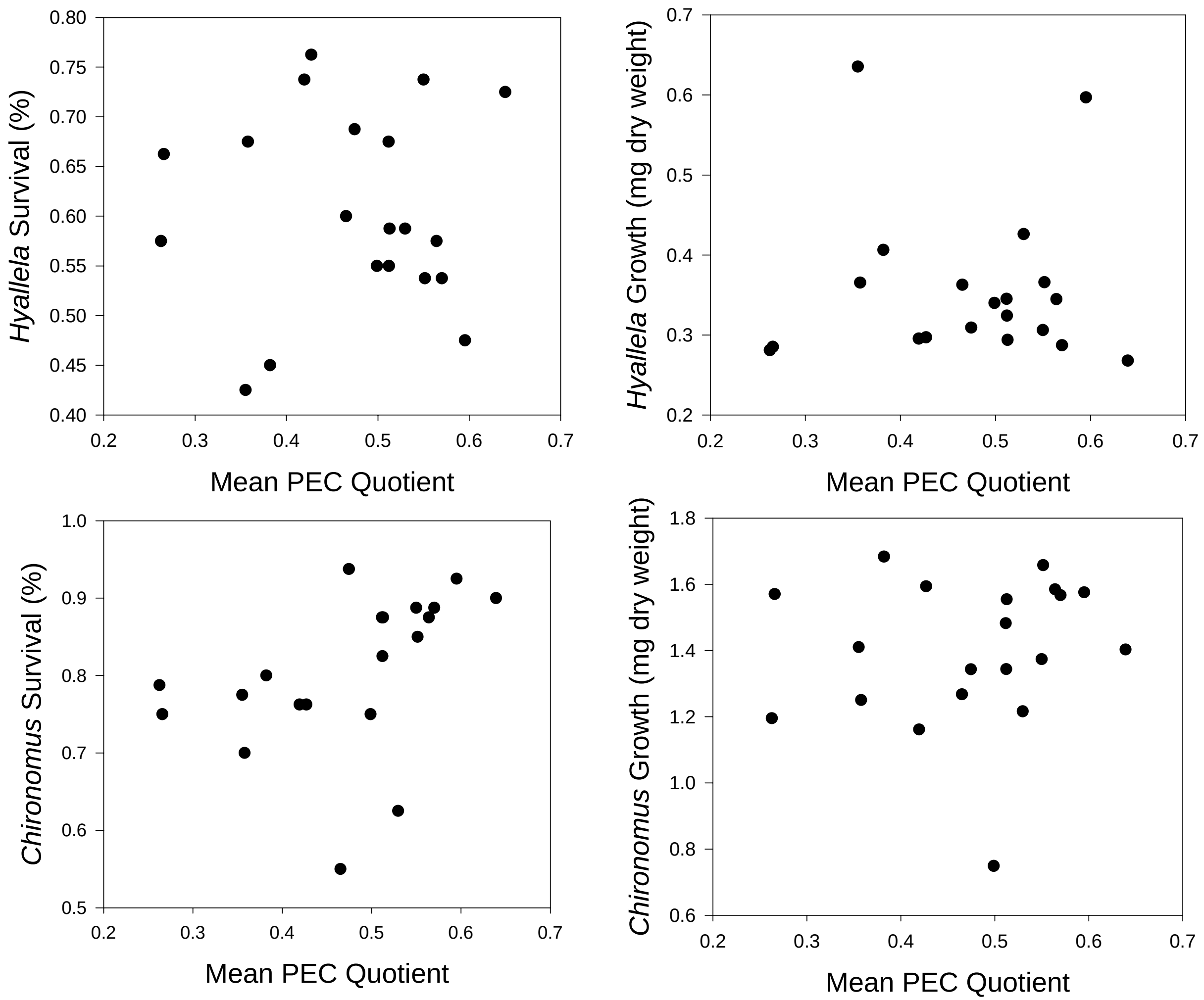

FIGURE 15
Toxicity Test Response
and Mean PEC Quotient

CH2MHILL

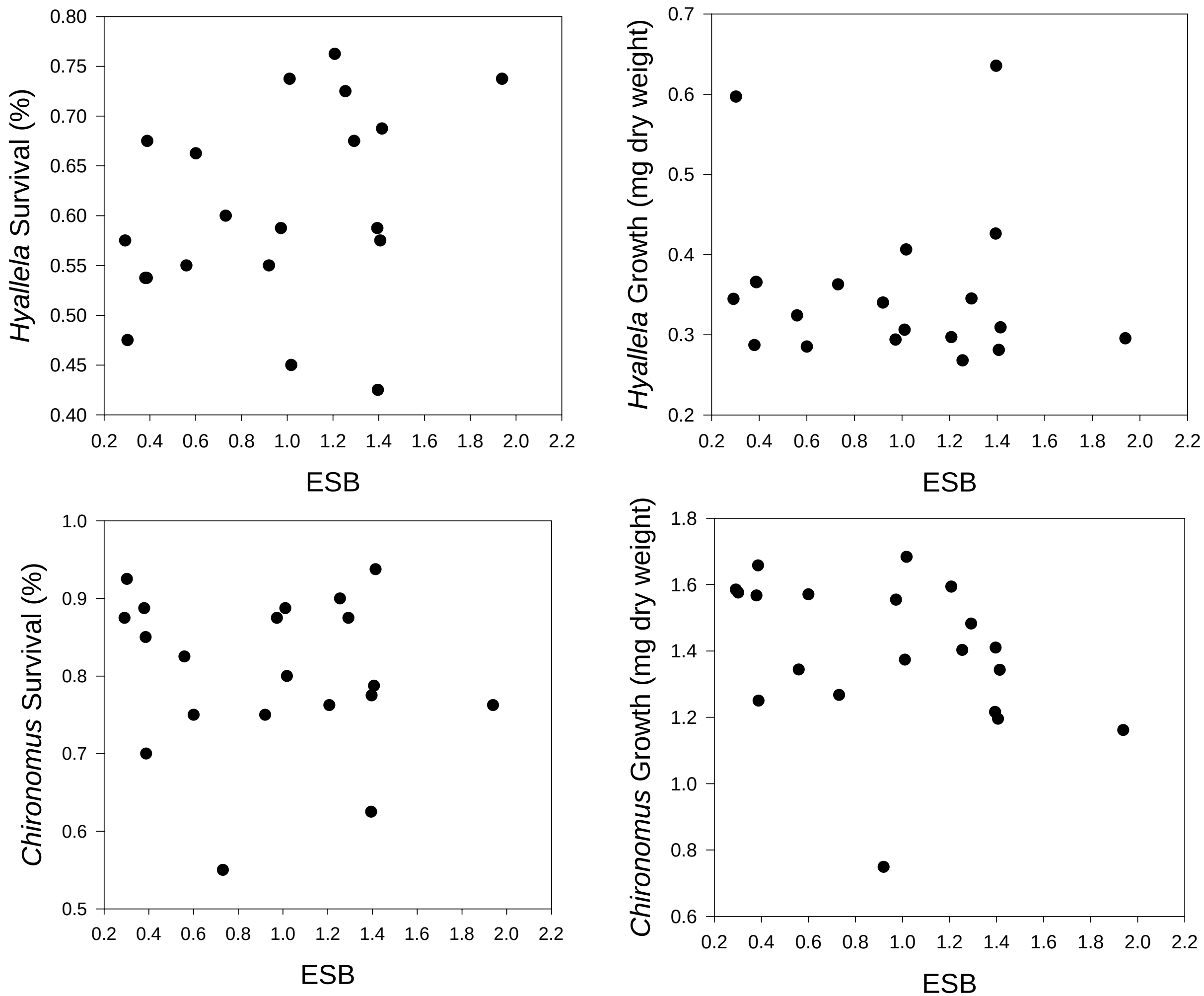

FIGURE 16
Toxicity Test Response
and ESB